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Science and Technology

(From the Month's News Releases)

Personal Road Signal

A tire-changing light and road signal called Save-Ur-Life has been put on the market to facilitate roadside auto repairs. It stands on its own base, has a 17-foot cord which reels into the base, a directed, continuous work light, and a flashing red light. Either flasher or work light operates alone.

The USDA and Science

The substitution of ground cobs from white or white hybrid corn or popcorn for cornmeal in making abrasive hand soaps is recommended by the Department of Agriculture. This would save a valuable food and make use of a waste product that meets all the requirements of a mild abrasive. Certain rural mills are already equipped to process cobs for hand soaps, since they are now grinding 200,000 tons of cobs annually for other industrial uses.

Dr. S. L. Emsweller, of the Bureau of Plant Industry at Beltsville, Maryland, has demonstrated that 10-minute microscopic examination of root tips of crossed lily seedlings can show whether the crossing will produce a true hybrid seed or an apomictic seed that will grow only an unmodified offspring of the mother plant. Such early determinations will save one to three years of greenhouse space and care.

2,4-D or a mixture of 2,4-D and methyl ester of napthaleneacetic acid sprayed on cauliflower two weeks before harvest will improve the keeping quality of the crop 10–80 percent. Growth-regulating substances have been used successfully by the USDA for a wide variety of purposes—from staggering the harvest period of pineapples to prolonging the blossoming time of Japanese cherry blossoms.

In response to the request of the Commodity Credit Corporation for 200,000 tons of potato flour for export, the USDA has developed a new process that costs less than two cents a pound. If bleaching and sorting are omitted, livestock feed can be produced for a little more than one cent a pound. Use of existing idle installations (such as distilleries) would cut the cost still further.

A combination of two methods of ridding airplanes of hitchhiking insect pests is being used by the Bureau of Entomology and Plant Quarantine: the application of such insect-killing formulations as DDT, pyrethrum, benzene hexachloride, and the like—which stick to aluminum and composition board surfaces and remain poisonous for many weeks—by the aerosol method, using carbon-dioxide gas as the propellant. Heavy dosages may be used, as the solutions leave no unsightly deposit, are noninflammable, and do not streak or smear.

Push-Button Phone Calls

By means of a new procedure called operator toll dialing, a single operator on the Bell System will ultimately be able to dial a number anywhere in the United States and Canada, completing long distance calls in a matter of seconds without the aid of other operators. Already in operation in New York City, toll dialing is based on the development of ingenious electronic devices. Each time the operator punches a key, a tone pulse is sent out over regular voice channels to the switching center. "Brains" in the switching equipment sort out the different audible frequencies in each tone pulse, interpret their meaning, and provide the electronic "hands" that assume much of the complex switching operation.

Invisible Watchman

A low-cost burglar alarm operated by a change in light level of the present modulated frequency is not affected by surrounding light.The light beam, which is invisible to the naked eye, is effective at from 2 to 250 feet and can be bent around corners or criss-crossed to protect large areas.

Fido

The Los Angeles Airport has installed the first commercial Thermal Fog Dispersal System, developed by Todd Shipyards Corporation. First used by the British during World War II, Fido is credited with the safe landing in dense fog of 2,486 aircraft and the rescue of 15,000 airmen. The System has been further developed by the Air Force, the Navy, and the CAA so that it is now capable of turning 75-foot ceilings into 300-foot ceilings, and visibility of ⅜ mile into more than ¾ mile, in two minutes at a cost of $200. "A 50-passenger airplane can probably 'Fido' in to Los Angeles Airport for about $3 per passenger." This compares with $8 to $10 per passenger for alternate field operation at Palmdale, California. Control of the entire Thermal Fog Dispersal System is completely automatic.

Publications

Study Abroad is the name of a handbook just issued by Unesco. It is available for $1.00 from Columbia University Press and lists 10,500 opportunities for international study in 166 fields in 27 countries, including the United States. The largest number of available awards is in the scientific fields, particularly medicine, public health, engineering, and chemistry.

The New York *Journal of Commerce* has recently published an 80-page booklet entitled *New Products and Services*, which attempts a comprehensive listing of industrial innovations of the past year.

Quadrilateral Amputee Civilian Clothing (PB 95836), published by the Department of Commerce, describes new developments in clothing and equipment for wearers of prosthetic appliances. The pamphlet of 24 pages is available at $3.75 per copy in photostat form, or in microfilm for $2.00, at the Library of Congress Photoduplicating Service.

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APRIL 1949

MORPHOLOGIC ASPECTS OF CANCER RESEARCH

BÉLA HALPERT

Dr. Halpert (M.D., University of Prague, 1921) is director of the Laboratories of the University of Oklahoma Hospitals and professor of clinical pathology at the School of Medicine. He has been on the faculties of Johns Hopkins Medical School, the University of Chicago, Yale University School of Medicine, and Louisiana State University School of Medicine. Dr. Halpert's principal work has been on the gall bladder and on various aspects of cancer research. His article is from a Sigma Xi lecture presented at the University of Oklahoma, Oklahoma City, November 18, 1948.

THE cancer problem concerns all of us. It is estimated that in the United States alone about 180,000 persons die of cancer every year. The chances are that in your family and in mine someone either has cancer now or will have cancer and will die of it. Though cancer has existed as long as the human race, the knowledge of its nature is hardly a century old. Most of the scientific information has been acquired in the past fifty years. Between 1900 and 1930 there appeared more than 12,000 articles dealing with the experimental aspects of cancer.[1] Today oncology, the science of neoplasia, has advanced so far that we now can recognize the limits of our knowledge.

For practical purposes cancer may be defined as an atypical new growth, derived from cells of the individual. It is atypical in that it does not conform to the cellular pattern of the site of its origin and in that it does not serve any useful purpose. Furthermore, it maintains its metabolic activities at the expense of the body household, to which it contributes nothing. Not all new growths, or neoplasms, are cancerous. Those that grow expansively, like a toy balloon, and remain encapsulated, compressing rather than invading the surrounding tissues, are called benign neoplasms. Cancerous growths invade, infiltrate, and replace the surrounding tissues. Because of the rapidity with which the cancer cells multiply and the lag in the formation of supporting stroma, areas of necrosis and hemorrhage are frequent. Cancer cells may become detached and carried by the lymph or by the blood stream to distant parts of the body. Here they set up new cancer foci similar to the cancer at the site of its origin. Cancer cells are endowed with extraordinary powers of multiplication; in fact, the life of cancer cells is geared to one principal activity, namely, to multiply.

I

Depending on the cellular origins and cellular patterns, cancerous growths are either epithelial or nonepithelial. An epithelial cancerous growth is called a carcinoma; a nonepithelial cancerous growth, a sarcoma. There is a fundamental difference between the two kinds of cancer: the surrounding tissues provide the supporting stroma and blood vessels for a carcinoma, whereas the sarcoma evolves its own stroma. In rare instances there is a combination of the two kinds of cancer, a carcinosarcoma, in which a sarcoma forms the supporting stroma for a carcinoma. Such neoplasms have been observed in the mammary glands of mice, rats, and men.[2]

Roughly, there are two lines of investigation of

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cancer: one experimental, and the other clinical. Experimental cancer research employs animals—mice, rats, guinea pigs, rabbits, monkeys, birds, etc. It investigates the origin, structure, nature, and behavior of cancer cells. It studies the susceptibility of the animal to certain neoplasms and the genetic factors in the spontaneous occurrence of cancer. For investigative purposes, cancers are produced in experimental animals by physical, chemical, hormonal, viral, or other carcinogenic factors. Further experiments are designed to test the effects of various therapeutic measures. Cancer cells are transplanted from one animal to another of the same or another species and are propagated in tissue cultures. Such experimental studies prove the noncontagious or noninfectious nature of cancer and the origin of cancer cells from cells of the host. They also demonstrate the survivance indefinitely of cancer cells when environment suitable for their multiplication is provided.

Clinical investigation of cancer concerns itself with human cancer. Since the nature of human neoplasia in general and of cancer in particular can be learned from human sources alone, the investigation of human cancer is of paramount importance. Any phase of research in human cancer may be rewarding, and the information gained may prove of immediate—that is, of practical—value in the recognition and treatment of neoplastic disease.

Perhaps the most urgent of fundamental problems is the origin of the neoplastic cell. Morphologic evidence suggests at least two lines of derivation for neoplastic cells. One of these is the anlage origin, another is origin from apparently normal cells. In the first group, cells left over in the process of evolution of the individual start to multiply and form a neoplasm. These are neoplasms of anlage or cell-rest origin. In the other group, an apparently normal cell is stimulated to multiply, and during the process of cell division a new cell, a variant with neoplastic properties, is produced.

Cells left over in the process of evolution of the individual are often observed. Nevi of the skin; islands of thyroid or parathyroid tissues; islands of cortical tissue of the suprarenal glands; aberrant pancreatic tissue in the wall of the stomach, duodenum, or small intestine and elsewhere; aberrant bile ducts in the wall of the gall bladder; epithelial cell nests beneath the mucosa of the gums and about the hypophysis may be cited as examples. These cell rests usually remain dormant. Under circumstances as yet undeterminable, however, they may begin to multiply and become parent cells of a neoplasm. Such multiplication may occur in early childhood, during adolescence, or even in adult life. The stimulation initiating the growth is possibly hormonal and related to that governing the growth of the individual. Such tumors of cell-rest or anlage origin reveal themselves by imitating the tissue or organ structure they originally were destined to become. Depending on the stage of development of the individual at the time when the cells became segregated, these growths may be simple neoplasms mimicking a tissue, or they may be mixed tumors mimicking an organ, or teratomas mimicking an individual.

A few examples may illuminate this concept. An adamantinoma is a benign neoplasm mimicking a tissue. It arises from ameloblasts, the cells that form the enamel of the tooth. This is an ectodermal epithelial growth, the supporting stroma of which is provided by the surrounding connective tissue. Such neoplasms usually occur about the jaw and occasionally at the base of the skull in the region of the *sella turcica*. Rarely, an adamantinoma has been observed also at other locations.[3]

Anlage tumors of the salivary glands provide an example of mixed tumors mimicking organs. The anlage tumors of salivary glands most commonly arise in connection with the parotid glands or along the lines of fusion of embryonal facial fissures, and occasionally elsewhere. They are composed of cells which may produce ectodermal and mesodermal structures. The ectoderm is represented by the epithelial elements, and the mesoderm by the presence of embryonal connective tissue, adipose tissue, endothelial lined spaces, young and adult connective tissue, hyaline cartilage, and osseous tissue. In this kind of growth both the epithelial and nonepithelial elements are a part of the neoplasm. Therefore, the cells which form the anlage for this kind of neoplasm obviously became segregated at a stage of development when the cells had not as yet acquired their dominant characters as ectodermal or mesodermal cells; hence, their ability to form either kind with equal facility.[4]

Teratomas are neoplasms containing tissue elements derived from all three of the germ layers. The anlage for such growths, particularly if they are small, must have become segregated near the blastula stage of the embryo. When such growths are large they probably are a part of single-ovum twins where only one of the twins developed fully and enclosed as a teratoma a portion of its brother or sister.[5] Teratomas arising in the ovaries or in a testicle are of different derivation. In these organs there are multipotential cells that can produce structures of all three of the germ layers. These teratomas represent not siblings but descendants of the individual.

The neoplasms of anlage origin just mentioned are usually benign. There are, however, many cancers of anlage origin. Most of them occur in infancy and early childhood. At this age not enough time has elapsed for a carcinogenic agent to become effective. The medulloblastomas arising in the roof of the fourth ventricle, the retinoblastomas, and the neuroblastomas of the suprarenal gland, which are genetically and structurally closely related, belong to this group. Hypernephromas, Wilms' tumors, which are usually carcinosarcomas, and a recently observed case of fibrosarcoma of the epididymis in a child are other examples.[6]

II

A second line of derivation for neoplastic cells is from apparently normal cells. Often normal cells are stimulated to multiply. During the process of cell division under the influence of some undetermined agent a new cell is produced, a variant with neoplastic properties. This appears to be the case particularly when neoplasms arise from the epithelial cells covering the surface of the body or those lining the respiratory, gastrointestinal, urinary, and genital tracts. Here a prolonged chronic inflammatory reaction frequently precedes the appearance of the neoplasm. Obviously, some carcinogenic agent has been active at these sites. At other sites, however, the carcinogenic agent may be at work without producing any detectable initial lesions, and the cancer may be discovered only at a fully developed stage.

There are no means at present of observing the actual transformation of a normal cell into a cancer cell. Although some investigators speak of precancerous stages, obviously such a state is hard to define. Cells fully differentiated for a special function usually lose their ability to divide and thus to multiply; therefore, such cells cannot become cancer cells. Only cells still capable of dividing may become variants with neoplastic properties—that is, cancer cells. It is uncertain whether a single such cell is the parent cell of a cancer or whether several similar cells at a given site become cancerous simultaneously or in succession.[7] The presence of a growth-promoting substance can safely be inferred as existing about the margins of the cancer, since all the cells near by appear large, their nuclei are more deeply stained, and the cells themselves seem less differentiated than those further away.

The nomenclature of the various kinds of cancer has not as yet been unified. The differences, however, are superficial rather than essential.[8] Each cancer usually has its individual cellular pattern, which is faithfully reproduced in every part of the growth and at all the distant sites where the cells have been transported and implanted. It is simpler to name the neoplasm according to the cell that forms the growth rather than according to the structures formed by the cells. The variations in cellular patterns of growths arising at the same site in different individuals can be explained on the basis of dominant and recessive characters of the parent cell of the growth. An ectodermal parent cell, for example, may grow in sheets producing no particular pattern; it may mimic the cell pattern it would normally produce according to its dominant character; or it may produce any other patterns for which it has recessive characters. The genetic method of nomenclature has been successfully applied to neoplasms of the central nervous system by Bailey and Cushing,[9] and more recently to carcinomas of the lung[10] and to growths originating at other sites.

The existence and nature of a neoplasm are established by microscopic examination. Since the cellular structure and pattern of a neoplasm usually provide clues as to its likely cellular origin and to its probable behavior, this information is of paramount importance in determining the method of treatment. Therefore, when patients have areas suspected of neoplastic involvement or lumps suggestive of a new growth, the lumps are removed or the suspected areas biopsied and examined microscopically. The pathologist to whom the tissues are submitted for gross and microscopic examination identifies the growth and determines its position in the oncologic system. The report he renders is usually decisive as to the course of treatment. Thus the scientific clinical investigation and study of human cancer require the understanding cooperation of patients and the coordinated efforts of a team of physicians.

Cancer teams are in operation in practically all well-conducted hospitals and particularly in those connected with university medical schools. These teams collect an immense number of objective clinical data by establishing standard methods of diagnosis, by applying standard and new methods of treatment, and by observing and recording the course of the disease during the patient's life. The tissues submitted for microscopic examination and those secured at post-mortem are preserved as part of a collection for immediate and subsequent study. Thus the laboratory of each hospital that cares for cancer patients is a potential center for cancer research. The record of each patient constitutes a unit of scientific information for subsequent study. From such centers there may come reports on large series of patients who had cancers in various organs or sites of the body. Observations are thus

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made available on cancer of the lung, stomach, pancreas, biliary system, intestines, genital and urinary tracts, brain, skeleton, soft tissues of the body, etc. that cannot be obtained in any other way. There may come reports on neoplasms never seen before,[11] or so rare that only a few are on record. Such reports may aid others in recognizing similar growths or may bring out new principles or shed light on obscure fields. The collection of individual records of cancer patients in hospitals having modern standards, the analysis of such records by statisticians, geneticists, morphologists, and other specialists, and the reporting of the results add to the knowledge of human cancer. Knowledge is gradually accumulating on the race, sex, and age incidence, on the cellular structure of cancer,[12] on sites of its origin, the methods of spread locally and to distant parts of the body, and on the effects of cancer on the host. Such information is being gathered while the fundamental problems are awaiting solution.

III

It must be clear from what has already been said that information is most wanting at the point where the cell of the individual becomes an atypical cell, forming either a relatively orderly growth pattern and becoming a so-called benign neoplasm, or forming a more disorderly growth pattern, a so-called malignant neoplasm, or cancer. In solving this problem experts in practically any one of the natural sciences may be valuable members of an investigative team.

The experimental research worker may choose animals with a short life span and through controlled matings study the behavior of a cancer through many generations. The research worker studying human cancer is at a disadvantage: his life span is the same as that of his subject, and matings remain uncontrolled. This is the reason why progress in the study of human cancer is so slow and painstaking and why it requires the cooperative efforts of many scientists with special knowledge.

Any field of investigation is enriched whenever new theories are evolved and new methods of investigation are discovered. Often the man with the technical skill is not the same one who evolves the theories that tie seemingly unrelated facts into one greater scheme. The discovery of the cell as the smallest unit of life in the tissue or organ, the invention of microscopic techniques, and the perfection of the microscope laid the foundation for morphologic identification of neoplasms in general and cancer in particular. We are still in the process of exploration with these tools. When new methods and techniques are evolved, they may permit the invasion of fields yet unknown, and new theories will provide the impetus for such exploration. It has often been said that a theory need not be true—it just needs to be good! That is, it should explain all the facts available at the time. When new facts appear which the theory cannot explain, it is replaced by a new and better working hypothesis. Let us hope that the interest now manifested in cancer research will yield new tools and theories that will eventually solve the cancer problem.

There are, of course, some obvious questions I am sure everyone would like to have answered. The two most urgent are: Is cancer on the increase? and, What can I do to protect myself and my family from getting it? Neither of these questions can be given a final answer. In my experience cancer *is* on the increase, and the reason for it is that people live longer and more people are alive in the sixth and seventh decades. It must be remembered, however, that cancer is quite frequent in children and occurs also during adolescence and in young adults. The second question can be answered only indirectly. According to E. V. Cowdry,[13] who skillfully summarized the work of the Fourth International Cancer Research Congress held in St. Louis last year, the general consensus of the Congress was that complete protection from cancer is impossible of realization. There are so many carcinogens, of both external and internal origin, that they cannot all be avoided. If by constitution and coincidental exposure to carcinogens one happens to develop cancer, one should look upon it as upon any other disease, have it diagnosed as early as possible, and have it treated in the best manner available.

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LA MONTANA LLORONA*

ARCHIE F. CARR, JR.

Photographs by Margaret Hogaboom and the Author

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TOWARD the end of April the high valleys of southern Honduras, which have lain waterless beneath the fierce tropical sun since November, begin to dry up. One can count the boulders in the once lush *potreros,* and the scant, green carpet has withered under the dusty pines on the mountainsides. The cedars and the stubby-limbed ceibas wait leafless for the rains of May; only the imperturbable mimosas, the *coyol* palms, and the figs and *guanacastes* along the watercourses relieve the brown monotony. The cows go dry; the steers are skinny and listless and seek shade in preference to the tasteless stubble. At night thin red lines snake along the flanks and summits of the mountains, where ground fires scavenge in the crisp remnants of the pine woods understory. The wind that sporadically sweeps up from the Pacific toward morning is hot, like air from Texas prairies or city asphalt.

Toward the end of April, too, our nerves unravel. We begin to get sick of the *verano,* with its blue haze of smoky dust, and its tough beef, and two canteens per rider per afternoon jaunt. Our spirits droop in the heat and drought, and we wonder pettishly if it will ever again be cool and wet. Our bitterness mounts with the realization that we must wait for the rains of June.

But is June really the only way out? How about the 6,300-foot peak of Uyuca that rises at the valley's edge only two miles or so away? And how about Portillo and Monte Crudo and El Volcán? They are all much nearer than June and are cool little isolated worlds, as abruptly disjunct and unexpected—and as welcome—as a palm-shaded well in the Sahara. Up there where the clouds cruise by on the unhindered trade wind, the pine woods give way and the *montaña,* the cloud forest, sucks water from the eternal mists and mocks the forty-inch rainfall of the valley below.

From various points in the valley around Escuela Agrícola Panamericana ten cloud-forested peaks may be seen. A visit to even the nearest of them means a long, hot climb, but the reward is great and the climb itself is interesting. It takes one out of the valley with its chaparral and coyotes into the

*As one wanders about the highlands of Honduras and asks the people the name of their highest local peak, the answer comes back, again and again, *"La Llorona;"* that is to say, *La Montaña Llorona,* which means "The Weeping Forest." The people thus allude, with characteristic imagery, to the tearlike fall of water that condenses on the trees of the cloud forest. How the word *montaña* came to mean forest is another story.

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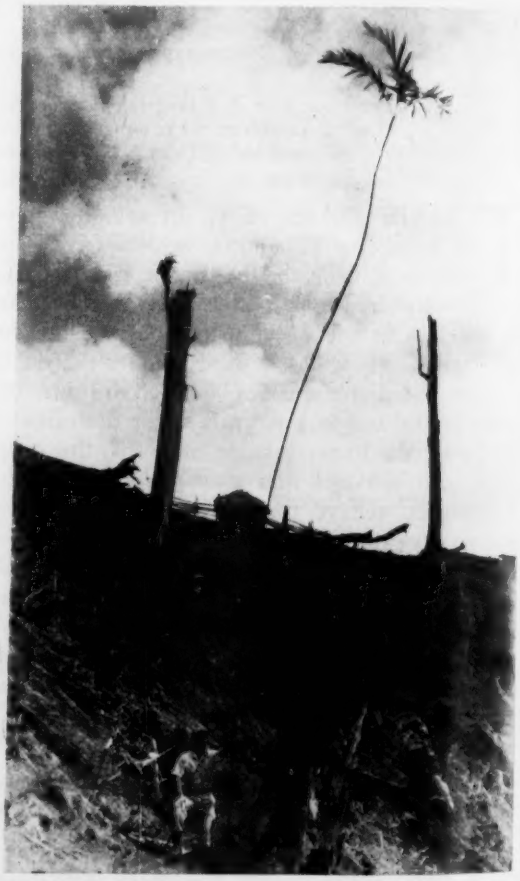
open pine woods of the surrounding hills, with a very different fauna. A couple of thousand feet of this parklike *ocotal*, and the *ocote* pine is replaced by another species, known locally as *pinabete*, often burdened with epiphytes and sometimes mixing or alternating with liquidambar, the familiar, beautiful sweet gum of the southeastern United States. Each of the transition areas between these vertical zones is the equivalent of many miles of latitude in the biotic changes it brings, and each tempts the biologist to tarry. But in the drought of April it is better to climb on, emerging from the *pinabetal*, crossing the fringing fields and blackberry tangles, pushing through the second growth *guamil* and passing at last between the outer columnar trunks of the *montaña alta*. Abruptly, midday changes to owl's-light, and the dry breeze behind is damped to a slow drift of air that is 8–10 degrees cooler than that in the valley, and heavy with moisture and the smell of wet plants.

The cloud forest community is primeval and self-perpetuating. As in most natural mesophytic climax forests, the talier trees meet above in a continuous leaf stratum, which opens only here and there to admit splotches of sunlight. Competition for light among the numerous species of gigantic oaks and *aguacates* leaves little for the plants of the dim understory to fight over, but tree ferns and spindly palms thrive, varying in relative abundance from one forest to another and occasionally attaining heights of thirty feet and more. Giant-leafed wigandias and a purple-flowered fuchsia glean light in the shadows. The curious tropical melostomes, with a host of species in the lowland rain forest and a few others in the dry uplands, here show their versatility in a whole new series of forms, which range in size from small shrubs to fair-sized trees. The smaller plants are tender, gloom-loving begonias, aroids and peperonias, pteridophytes and mosses in endless variety, lichens, liverworts, and algae, all of which grow equally well on the ground and on the grotesquely buttressed, deeply fluted, and vine-embraced trunks of the older trees.

It is next to impossible to look up and determine with certainty which leaves belong to a particular tree. The confusion of interlacing branches is complete, and a tree which bears, say, 3 tons of leaves may, according to my reckoning, support 5 tons of epiphytes ranging in bulk from microscopic algae, tiny mosses, and half-inch orchids to enormous thick-leaved, woody parasites, one individual of which may replace a third or even half of the original tree crown. On one 18-inch length of tree-fern trunk I was able to find 24 species of plants, and I am sure that a botanist would in several cases have distinguished between species that I lumped together. On the drenched and windy peak of El Volcán I climbed a tree which was twisted and wind-pruned like a tree on ocean dunes and which had the usual investment of mosses, selaginellas, and filmy ferns concealing every inch of limb surface. Besides this, it bore four different kinds of leaves in approximately equal abundance, and I would have challenged any botanist to determine which belonged to the original host trunk without making a laborious dissection of the tree.

In the high but protected and relatively level coves and glens, such as the superb Plano Aguacatal in the San Juancito range, or the little hidden plateau where the waters of the Santa Clara arise on the slopes of Monserrat, a number of oaks, *aguacates*, and other trees unknown to me, grow to immense size, and the forests surpass in stateliness anything in my experience.

To me, however, the dominant plants of the cloud forest are not the giant trees but rather the



A skinny palm of the genus *Chamaedorea* from a deep cloud forest on El Volcán.

Epiphytic cacti hang from trees in the San Juancito Mountains. In June these pendant ropes bear lovely orange-colored blossoms at the ends.

epiphytes. The most important factor in the development of these woods is water vapor—not precipitation—and the air plants, high and low, respond more directly to this influence than those with roots in the ground. If a tree wins out over its neighbors and rises above them, thousands of unbidden guests seek to share its advantage. They pile up in sodden tons on the trunk and branches and crowd the leaves at the tips of the slenderest twigs. During heavy rains the added burden of water they hold is often too much for the great limbs, and they may crash to the ground, ripping out sections of the trunk as they fall. Apparently, the normal ultimate fate of the big forest trees is to be overcome by epiphytes, insidiously, leaf by leaf, or by catastrophic collapse, or by a combination of the two.

The dominance of the epiphytes is particularly obvious in the exposed levels above 6,500 feet, where the large-leaved trees of the protected places are replaced by heaths, *Podocarpus,* wax myrtle, and other small and hard-leaved species. It is difficult to explain this transition to a dominantly ericaceous flora on these high peaks which receive a maximum of water through condensation of moisture from the nearly continuous winds, unless it be that the stronger winds augment the hazard in a temporary failure of the moisture supply. These scant-leaved, dwarfed, and wind-tortured trees are often little more than framework for the support of masses of air plants, and a tree that at first glance appears to be alive may be nothing but a corpse, completely enshrouded by the flora that killed it.

At 7,500 feet on Peña Blanca the vegetation is a wild, unsorted hodgepodge. There is no distinguishing between limbs, trunks, and roots, for all loop and twist and sprawl about on the steep rock faces beneath a heavy, wet mat of lower plants. Only here and there a plume of leaves projects from the crazy mass to mark the site where a tree is trying to make a living in the face of almost insuperable obstacles.

A feature of the cloud forests almost as striking as the lavishness of their plant life is their relative poverty in animals, a poverty both in species and in individuals, but most markedly in the latter. Expecting to find a luxuriant environment supporting a dense and varied animal population, one enters the woods prepared to marvel at the fauna. It is entirely possible to wander about for hours, however, and even for days, amid this floral splendor and see only a little more in the way of animals than might be found in a well-kept greenhouse.

To illustrate the sort of jolt which this hothouse sterility delivers to one's preconceptions, consider the case of the bromeliaceous air plants. It would be hard to mention a minor environmental

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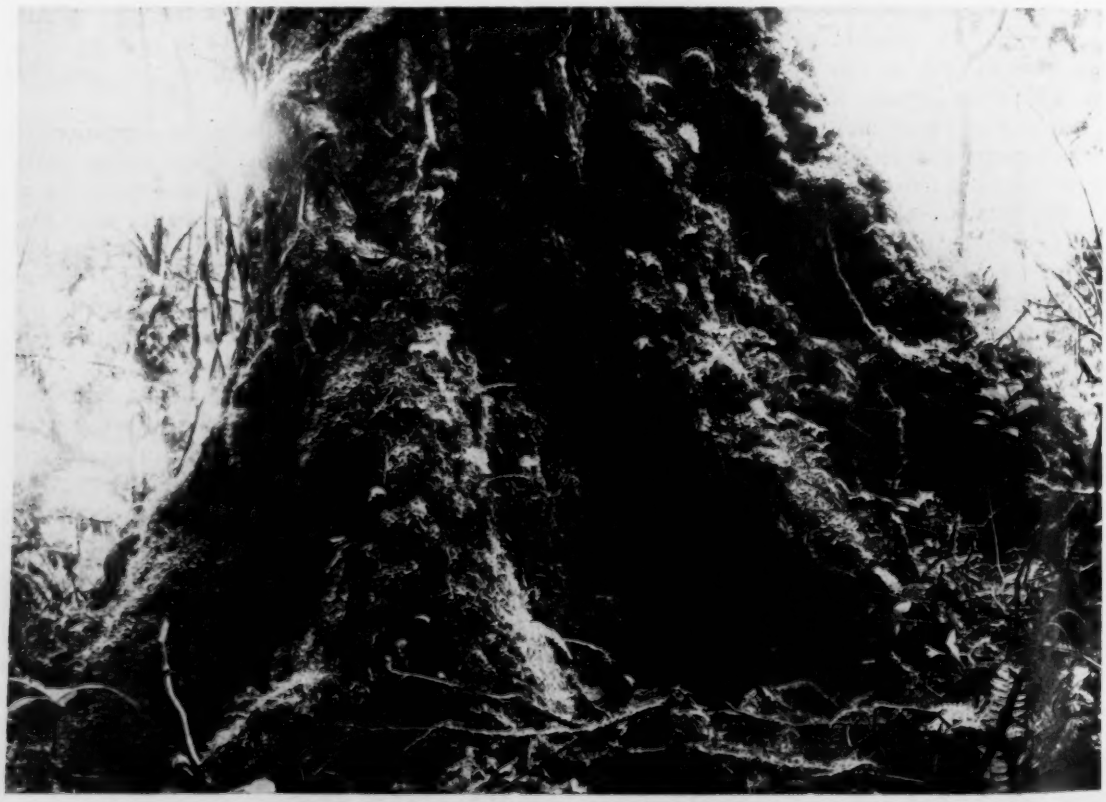
niche which holds, and usually fulfills, more promise for the herpetological collector than these epiphytic, water-storing plants of the pineapple family. In many regions, if a bromeliad can be found, the reward of from one to a dozen or so specimens is almost automatic. In the tropics, humid or semiarid, the smooth, broad-based leaves and nearly permanent axillary pools of cool water offer irresistible quarters for various species of frogs, salamanders, lizards, snakes, insects, and mollusks, and some of these have become drastically adapted in structure to life in air plants. These facts are well and widely known, but to the seasoned collector who, reading this, may find their repetition tedious I suggest that he go with me to Portillo de los Arados. Here the forest climbs a 60-degree slope from a fern-shaded spring and rill among the rocks to the tip of a 6,000-foot peak, and the trees bear more bromeliads than I ever saw before. Or, rather, I should say *bore* more bromeliads, because I think we clawed down half of them in the excitement of our conviction that here, at last, we would find salamanders on the Pacific slope of Honduras. We hauled them down, one after another, dumping upon our shivering persons the quart or gallon of cold water that each contained and finding not one single vertebrate animal. Of invertebrates there were only some sow bugs, an occasional centipede, several scorpions (one of which stung me), and swarms of ants (nearly all of which stung me).

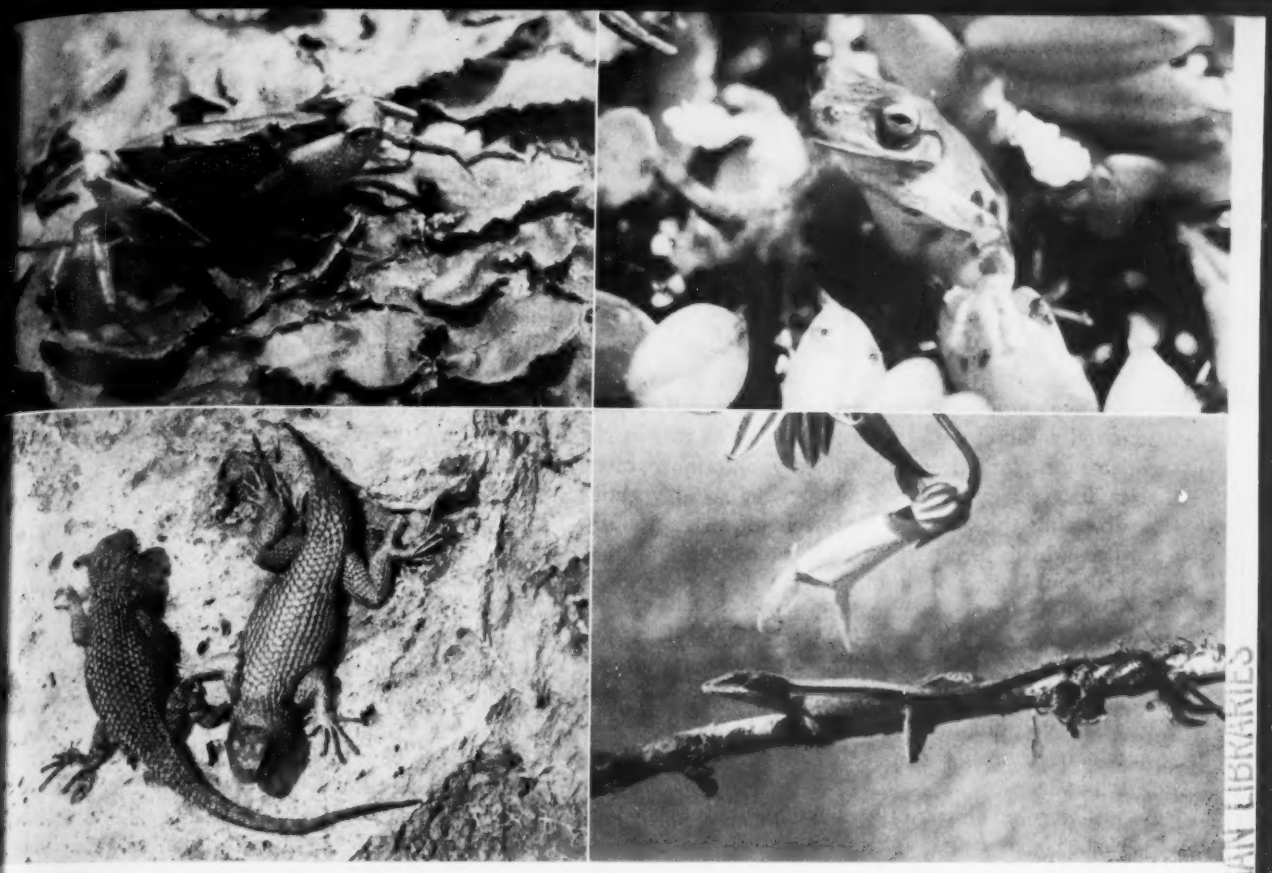
After that, we sulked in the valley for nearly two weeks and did not go near the high woods.

But this was a mistake. When finally we returned it was to spend the night in a tiny milpa deep in the forest of El Volcán. We slept on the ground and were awakened in the vaporous dawn by the ethereal songs of scores of *jilgueros,* the incomparable notes of which express so precisely in fluid sound the spirit of the high forest. We lay under our tarpaulin watching the heavy white mist drift over us and listening to the ecstatic notes of the unseen birds, singing in a cloud, and forgot for good the fiasco of the bromeliads.

Much later, on this same mountain, I had the supreme reward of seeing my first male quetzal. It was 5 : 30 in the afternoon of a day spent in fruitless search of quetzals. We had scaled the dripping peak of El Volcán, descending it on the opposite side and laboriously working our way back around the base to the homeward trail. As the sun was setting we crossed a little clearing bounded by the towering silvery trunks of the primeval forest. I sat down to spend the few remaining minutes of daylight



The buttressed base of a giant *aguacate* at Rancho Quemado.



Upper left: This little crab is one of the very few inhabitants of any size of the icy brooks and springs of the highest forests. *Right*: A cloud-forest tree frog peers from a cluster of diminutive orchids. *Lower left:* The coloration of this spiny-scaled mountain fence lizard varies from bright green to sooty black. It lives on dead logs in clearings in the cloud forest. *Right*: A female anoli from an elevation of 7,000 feet at Rancho Quemado, San Juancito Mountains, type locality of the subspecies.

watching the forest border for anything that might emerge while my companion went to fetch the horses. The brief sunset spread flame through the clouds behind the western ranges, and desultory shreds of mist began to spiral down into the milpa. For once there was almost no wind, and the only sounds were occasional incredibly sweet passages from the *jilgueros* and the low, duotone chant of the Mexican trogon in the depths of the forest. Suddenly a harsh cackling call came from a tall tree at the edge of the woods. I rose and walked toward the tree while the call continued. As I approached, several green toucanets emerged from the tree and flew off over the milpa, pushing their banana-like beaks before them. The raucous cackle continued. Then three quetzals, a female and two gorgeous males, rose above the crown of the tree. One of the males and the female flew directly into the woods, but the other flew and hopped from one tree to another, often making vertical sallies into the air above and descending again in a wholly uncalled-for series of swoops and dips and pirouettes to display his crimson breast, the blue-green fire of his wings, and the grace of his yard-long tail. This was reward enough, and indeed if the forest grew for no other end than to support this bird it were no waste.

There is a handful of animals which a quiet observer may see on nearly any given visit to any of the local cloud forests. These creatures are for the most part species endemic to montane communities and have wide but necessarily discontinuous distribution throughout Central America. Like most habitues of deep forests, they know how to live inconspicuously in the background of their environment.

If you want to see them you will have to sit on a log and wait. If your log lies at the edge of a clearing you will almost immediately see on a near-by stump a big green or sooty-black fence lizard of the genus *Sceloporus*. If the time is early morning or late afternoon, or if the clouds are drifting through the forest on a gentle wind, you will not wait long for the songs of the *jilguero* or nightingale thrush and the black robin, known here as *sinzontle*. Both are skilled ventriloquists, and, though they may render their flutelike arpeggios from no more than a few yards away, they are very hard to see. Long before you locate a singer a flock of clorospingas will pass by in the lower trees, squeaking as they hop from one berry-bear-

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ing twig to another. If you continue to give no offense a slim brown wood hewer will swoop down to a near-by tree and stay to forage a bit.

A slender anoli will scurry along a vine and stop to spread his orange throat fan; or to nap for a moment in a splash of hot sunlight, with arms tucked in and legs pressed back against his tail; or perhaps to creep up with horrid stealth and seize a simple-minded cranefly. A small, short-eared squirrel that has been looking at you in silence for a long time will suddenly materialize, often under your very nose, and try to scold without dropping the avocado that it holds in its mouth. These little forest squirrels are common and unafraid and ask only that you keep the peace.

Sooner or later you will become aware of a tiny, intricate song, sung in an excited whisper somewhere close by. This is Rehn's mountain wren, through some ornithologist's whimsey, and when you finally locate the red-brown dwarf it will have been within reach of your hand all the while.

The robin chirp of the dusky *zorzal* is never long still. Usually the woods echo also with one or both of two other bird calls, one the monotonous and incessant single note of the white-faced quail dove and the other the brooding chant of the Mexican trogon.

Among the few actually conspicuous inhabitants of the cloud forests are the hummingbirds when they are in season. They are of a dozen or more species, and to the eye accustomed only to the common ruby-throat of the United States their variety in size and coloration is striking. They range from tiny mites noticeably smaller than the ruby-throat up to a glossy dark species with a body the size of a man's big finger. During September and October, when the wild *aguacates* bloom and the melostomes and vacciniums strew the ground with shed corollas, the hummingbirds leave the fields and *guamil* and blackberry tangles and move into the depths of the forest in hordes. They suck the high blossoms and make their perfect little nests of live moss covered with lichens and lined with the silken fiber of the tree fern. Their voices are as various as their shapes and sizes, and the males scold and squabble incessantly. One misanthropic species marks the course of any intruder who walks through the woods by repeatedly taking stations on twigs just in front of him and uttering raucous cheeps in outraged monotone, once a second without ceasing until the trespasser has crossed the bounds of what the bird regards as his rightful freehold. Another species vents its seemingly chronic spleen by zigzagging angrily among the trees around the human visitor, often diving at his head at breakneck speed, and all the while rattling out a querulous complaint for all the world like a midget kingfisher. Among themselves they fight bitterly and often, and their quarrels are both intra- and interspecific without bias. If one lies on one's back and stares upward at the level where the treetops interlace high above, one may see pairs of buglike hummingbirds zipping over and under the green canopy like dogfighting planes diving into and out of cloud banks. One such pair may suddenly plunge downward in a breathless spiral, the hind bird following in machinelike detail every intricacy of the mad course of the pursued. They may collide in mid-air in front of the observer's face with what ought to be crushing force and then fly separately away to sit on twigs and preen and await the fine new surge of anger that will tune their incredible little muscles for more joyous combat.

Hummingbirds are birds apart. They are miracles of mechanical design and physiologic efficiency. Their initiative and courage are beyond reproach, and in many species the splendor of their coloring cannot be matched in the biologic world. But few who know them will go much farther in their praise. For the rest, they are peevish and restless and generally ornery and are no comfort either to themselves or to anyone who lives with them.

Of invertebrate animals the most noteworthy—in its abundance as well as in the incongruity of its occurrence on a mountain peak—is a crab. To me, a crab has no business in fresh water and much less in a cloud forest, and I still feel an irrational sort of skepticism every time I see one. The small, black mountain species lives in the beds and borders of foaming creeks and rills and around the near-by springs, where it digs caves under rocks where salamanders should be and heaps up mud pellets like crayfish should do.

Perhaps of just as much consequence in the forest community as any animal that I have mentioned are the several kinds of mice and at least two species of shrews that live underground in the root mazes, but they are almost never seen unless trapped. It is also easy to miss the glistening, yellow-speckled plated lizard that hunts sow bugs and wolf spiders and spindly-legged crickets in the leaf mold.

Besides the few common and characteristic denizens that one can count on meeting on almost any trip into the *montaña*, there is a long list of creatures which are seen only sporadically, or very locally, or perhaps not at all and which the forest holds in reserve to shock the observer out of

any growing smugness over the authority of his lore. Thus, only one time, after hundreds of hours of observation, did we encounter an anteater, and on the same day we collected our first and only penelope—the big burro-voiced *pava*—when we walked up under a pair eating berries in a tree at Rancho Quemado. We had hunted deer and frogs on Uyuca so many nights that when finally our lights struck red fire from eyes in the trail ahead we only stared stupidly as a puma loped slowly up into the darkness and *guamil* above. These animals of rare occurrence not only lend the promise of drama to every collecting trip, but the very eccentricity of their distribution may present problems of irresistible interest to the zoologist.

Hummingbird's nest from the windy peak of Uyuca. Constructed of live mosses, it was camouflaged with lichens and lined with the silky fiber of the tree fern.

For example, consider the faunal vagary to be seen in the colony of giant pocket gophers on a mountain in El Paraiso known as Portillo de los Arados. Here the forest has been skinned back on all the slopes up to the sheer crest, which is crowned by a *faja de montaña*, a long narrow strip of well-developed cloud forest. In the margins of this woods and in the milpas which skirt it, the ground is honeycombed by the burrows of an enormous pocket gopher, which we have seen on two occasions but have not succeeded in collecting. Neither the soil nor the vegetation of this mountain shows any notable difference from those of other mountains that we have visited. The only place in Honduras where pocket gophers are known is Alto Cantoral, north of Tegucigalpa, which is the type locality and only known range of the Honduran pocket gopher, a subspecies of the giant pocket gopher, and probably the same animal which occurs on Portillo. It seems very unlikely that we have merely missed them elsewhere, since their excavations and mounds are very conspicuous and would be next to impossible to overlook. Whether Portillo furnishes the gophers with something vital which is wanting on the other peaks, or whether their restricted distribution refers instead to some event in the history of the region or of the race, is an intriguing question and one which almost certainly would repay a systematic study.

Another case of interest is that of the quetzal. This incomparable trogon is a characteristic inhabitant of cloud forests from southern Mexico to Panama. Because of its superb plumage it has been persecuted unmercifully in many places, and its scarcity in suitable areas around the larger towns is probably due chiefly to the work of hunters. But in the rural, south-central part of Honduras, where

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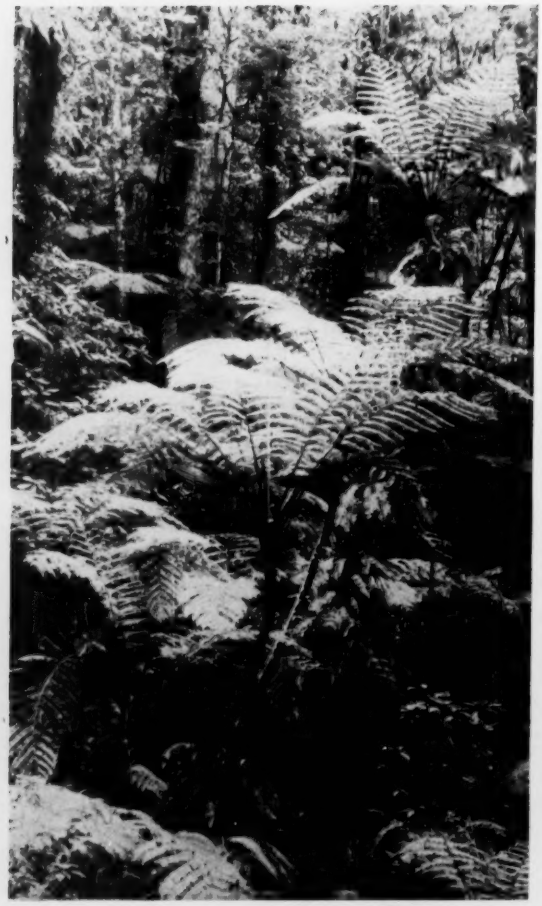

Tall tree ferns from interior of the forest of Uyuca at an elevation of 6,000 feet. Vegetation is characteristic of the more protected glens and ravines.

our series of cloud forests is located, guns are scarce and where found are usually muzzle-loaded with black powder and a quarter-inch cube of bar lead. They are not often used for shooting at birds and even less frequently for killing them.

It seems probable that here the infrequent occurrence of quetzals is due more to the restricted extent of the individual forests than to the killing of birds. At San Juancito there is far more hunting than in any of the other local forests, and yet the quetzals hold on within sound of blasting at the Rosario mine, because the woods there is almost unbroken over thousands of acres. Likewise, we found quetzals in the Yuscaran Range around El Volcán even though the 15–20 square miles of cloud forest there are spotted with *ranchos* and dissected by cultivation. In the smaller forests, however, such as Montañuela, Portillo, and Monte Crudo, although the physiognomy of the vegetation is identical, quetzals are entirely unknown.

In this case the limiting factor would appear to be food. Quetzal existence apparently depends upon a continuous abundance of small fruits. There is evidently an areal threshold below which a given forest is too small to yield these fruits in perennial supply. The birds venture from their primeval habitat far enough to augment their diet with the luscious blackberries that abound in the marginal tangles (as do also the peccaries and, where found, the mountain tapir), but they evidently never migrate and are actually prisoners in their cloud-swept jungles. If the fruit crop fails for a single week they must starve.

Of equal interest, zoologically if not aesthetically, is the *tamagas* of San Juancito. The *tamagas* is a short, fat, irritable viper of the notorious genus *Bothrops* (*B. godmani*), which includes the *barba amarilla* (fer-de-lance), the horrendous bushmaster, and a host of smaller poisonous snakes. The curious thing about the *tamagas* is that the only ones we have ever seen were at Rancho Quemado in the San Juancito mountains, where they are quite common. In the places where the sun filters down through a break in the tall canopy overhead, they lie around on the leaf mold, their brown and gray color tones and rough scales making them as inconspicuous as mounds of leaves.

We have visited Rancho Quemado eight times and have only twice failed to see *tamagas*. Al Chable found four in one morning, and fifteen minutes after I had warned Margaret Hogaboom to watch where she put her feet she stumbled over a *tamagas* in the trail. I have collected in Honduras for three years, and the *tamagas* of this colony are the only snakes in the central part of the republic that I should call common. Only here, for instance, would I dare predict that on a given afternoon a snake-collecting jaunt would yield something.

The question of what attraction Rancho Quemado holds for *tamagas* is no great mystery. It gives them deer mice in abundance and an endless system of galleries and intricate moss-lined catacombs beneath the prop and buttress roots of the forest trees. Here they can prowl and forage in comfort when the blood-thickening fog is down and the icy drip turns *tamagas* bodies to lumps of helpless clay. The mice and the catacombs make for what would appear to be an ideal viper environment, and the *tamagas* respond with enthusiasm. Why, then, have we looked in vain for snakes of any kind in identically tunneled and mouse-filled areas in all the other forests?

I believe I know why the *tamagas* do not occur on the other peaks. I think peccaries make life impossible for them. The collared peccaries are ubiq-

uitous despoilers of the cloud forests. We have found their tracks or their dung or the wreckage they leave behind in nearly all the forests of the area. They live in the dense *guamiles,* preferably in the ghastly *morales,* or nearly pure stands of giant blackberry bushes, which fringe all the high woods; here the pigs are safe from molestation by man or beast. Part of the time the bands stay in the margins and eat blackberries, but often they come out to make forays into the milpas below or into the forest above. They are keen foragers and are apparently omnivorious, and I imagine that very little that is conceivably edible escapes their jaws. I would not give two cents for the chances of a fat and succulent viper, stupid from overeating or torpid from cold.

Heavy cloud forest above La Tigra, San Juancito.

Since the pigs do not dwell in the depths of the woods, but rather in the blackberry tangles at the edges, the snake population of a large unbroken tract of forest such as San Juancito is practically insulated from the ravages of the peccaries. On all the other mountains, however, the ratio of *guamil* to *montaña* is so much higher that no section of the woods escapes the sporadic patrols, and snakes cannot survive.

To me, the most curious anomaly of all is the mountain tapir. It outrages my sense of fitness. The mammalogists mostly recognize only one species of tapir in Honduras and so would have us believe that it is one and the same beast that wallows in the creeks of the coastal jungles and scampers about the crags of Chile Mountain. This may be so, but if it is I know of no more impressive example of ecologic tolerance and the broad, flexible outlook. I lived for a month on intimate terms with tapirs in the Nicaraguan rain forest and feel that I know something of their character and aspirations. I cannot believe that the tapir there is the animal that makes the tracks and trails on sheer cliffs of 6,500-foot Pico de Navaja, or ambles about the subalpine *morales* of Batea, picking blackberries, or that ran 6 miles along the knife-edged *fileta* of Cerro Brujo to elude completely a gang of mountain-bred dogs. How could the semiaquatic monster of the Huahuashan swamps slake his chronic thirst or cool his hide on the streamless ridges of Bromadero? I don't believe he does; I think it is a different creature and shall cite one minor aspect of jungle tapir personality to support my stand.

A lowland tapir descends the slopes of ravine-side or river bluff in a manner wholly his own and

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altogether irresponsible. If he arrives at such a declivity at all pressed for time he merely lets go and falls down. His legs move and usually manage to keep him right side up, but they in no way retard the acceleration of gravity. I have seen and heard this phenomenon several times and each time I marveled when the tapir failed to kill himself. On Chile Mountain he *would* kill himself. We climbed tapir trails there which required more from the arms than from the legs, and which would demand caution from a mountain goat. Any tapir trying to save time on these trails by falling down them would wind up in the vicinity of Cantarranas, some 4,000 feet below and 8 miles to the westward.

A comparison of adequate series of specimens of tapirs from the mountains and lowlands seems to me very much in order, and I strongly suspect that when made it will show at least racial differences between the two populations.

As a biotic environment, the Honduran cloud forests offer the biologist a challenge and promise of reward that would be difficult to duplicate. But, more than this, they hold an aesthetic appeal that is as deep as the mystery of the dim, green woods and as varied as their many changing aspects.

A mature female *tamagas*.

IS ECONOMICS NECESSARY?

KENNETH E. BOULDING

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BEING an economist, I can hardly be expected to answer "No" to the question that forms the title of this paper. My thesis is, however, that economics is necessary, not merely for the support of economists, but for the development and perhaps even for the survival of science in general and the civilization that supports it. I propose to consider particularly what justification there is for a separate discipline of economics, and what contribution this discipline makes to the general advancement of knowledge.

The social sciences are reputed, at least in popular imagination, to be less "successful" than the physical sciences. The "success" of a science is judged mainly by its ability to predict or to control future events in its field. For the common man, as for the operational philosopher, knowledge is identified with power, and knowing with know-how. By this standard even economics, which has a certain reputation as the most successful of the social sciences, makes a poor showing compared with the prediction of eclipses, the certainties of chemistry, and the miracles of genetics. This, we hasten to explain, is a result of the difficulties of the science, not of the inadequacies of the scientist. We sympathize with the wayward universe of the meteorolgist even as we chafe at the waywardness of his predictions, and, if the predictions of the economist are even more wayward, it is because of the complex and unstable nature of the universe with which he deals. Moreover, the social scientist faces a problem which normally does not bother the nonsocial scientist, in that he is himself part of the field of his investigation. If the heavenly bodies were themselves moved by astronomers, or even if they were moved by temperamental angels who guided their behavior by the astronomers' predictions, the astronomers would find themselves in just as bad a fix as the economists. The bacteriologist who must stain his bacteria in order to see them would be in even worse trouble if his bacteria blushed when they were observed. Of course not even the astronomer seems to be exempt from observer trouble in these days of relativity, but in the case of the social sciences the trouble develops long before we approach the speed of light. Nowhere is the positivistic fiction of a dispassionate, objective observer wholly removed from the field of his observation more absurd than in the social sciences. The difference between the social and the other sciences, however, is merely one of degree, and as the nonsocial sciences run increasingly into observer trouble it may be that not merely the results but the methods also of the social sciences may be of interest to other scientists.

Economics has a certain reputation—not, I think, wholly undeserved—for being the most scientific of the social sciences. It does possess, I think, a larger body of analytical propositions that are widely accepted by competent persons than either sociology or political science. It also exhibits the marks of the history of a true science, in that it exhibits an orderly development toward greater and greater generality. The older theories —i.e., of the classical economists—can easily be formulated as special cases of the more general modern theory. This very internal consistency and success, however, has developed in some economists a certain spiritual pride which has injured the development of social science as a whole, and I think the profession is coming to realize more and more the necessity for trade among the various disciplines if further specialization is to be fruitful. We are reaching out on all sides today toward a unified social science—a regional federation, as it were, which must be accomplished before we can proceed to that great federation of all knowledge that is the ultimate task of the inquiring spirit. All the social sciences have much to learn from one another, and the same might be said of sciences of any kind.

I

Economics, like any other science, has two closely related parts—the pure science and the empirical science. Pure economics is a branch of logic or of mathematics (in these days there does not seem to be much distinction between them). It attempts to construct systems of hypothetical

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propositions, mainly of a qualitative nature (if *A* rises, *B* falls) relating certain "economic quantities" such as prices, wages, outputs, interest rates, etc. Such a system is called a "model," and the construction of such models is, of course, the characteristic activity of the "pure" part of any science. The nature of the models themselves, however, is determined mainly by the empirical content of the subject matter of the science. Thus, even though the model is an abstraction, not depending for any correspondence with empirical reality for its self-consistency, yet the act of model-building—except perhaps in pure mathematics—is not unrelated to the empirical interests of the model builder, and the usefulness of a model depends on the degree to which it helps in interpreting the complexities of the empirical world. The Keplerian theory of a single planet revolving around a sun is a good example of an "astronomical" model. It has no exact counterpart in reality, at least in our solar system, yet it derives interest and significance from the fact that it helps to interpret (by being capable of extension and generalization) the movements of the actual solar system. Similarly in economics the marginal analysis of the individual economic unit (planet!) or the Walrasian system of equations of general equilibrium of the price system under perfect markets (which corresponds somewhat to the Laplacian system in astronomy) is a "model" which derives interest from the light it throws on the workings of the intolerable complex of social relationships. Models which do not apparently abstract from an empirical universe may be called "non-Euclidian" models from the analogy with non-Euclidian geometry. Thus it would no doubt be possible to construct models of planetary systems assuming different laws of gravitational attraction, of momentum, etc. than those which seem to prevail in our system; indeed, I have no doubt this has been done. Nor are these non-Euclidian models mere idle exercises of an overactive mind; they may turn out to have more than an aesthetic value, as witness the significance of non-Euclidian geometries in modern physics. In economics also there is something to be said for model-building for its own sake, and there is no need whatever to stick to the assumptions of the elementary textbook. Economics is in no way bound to such assumptions as profit maximization; there never has been an economic man even in economics, except as a very first approximation, and by means of the indifference curve analysis economics has increasingly liberated itself from any narrowness of assumption. The *methods* of economic analysis would apply just as well to a Franciscan economy as to a Benthamite! Nevertheless, the *interests* of the model builder are likely to be determined to a considerable extent by the empirical world in which he lives, and even by the practical problems he faces. It is no accident, for instance, that the depression of the thirties was the scene of a great deal of theoretical activity centering around the problem of unemployment. Similarly, in the elementary theory of the firm, the assumption is made that the firm selects that position of the variables under its control which results in the maximization of some measure of money profits. As a first approximation, this assumption yields useful results. But it is quite possible, and indeed necessary, to go beyond it, and to take account of more complex motivations, such as the desire to be important,* or to be well regarded, or to obey the dictates of conscience, or even to be liquid.

It is not generally realized, I think, how far economics has gone in the direction of becoming a generalized theory of choice. Economics begins as an attempt to explain the magnitudes and movements of certain quantities, such as prices, wages, outputs, sales, and so on. Very early in its development it became clear that these quantities cannot be treated as an independent world of their own, for they are thrown up as a result of the whole complex of human choices operating within the strait jacket of a niggardly natural environment. Thus even in Adam Smith we find the explanation of wage differences in terms of what might be called the nonmonetary advantages of the various occupations; and little more than a hundred years later we find Wicksteed illustrating the principles of value theory with reference to the problem of how high a cliff one would dive off to save a mother-in-law, or how much family prayers should be shortened to speed a parting guest to the train—problems that are a long way from what is usually thought of as economic. Nevertheless, it is an inevitable logic that has turned the study of prices into a theory of value, for the price system is simply one reflection of the general problem of "scarcity," and the choice between nuts and apples differs only in its simplicity from the choice between income and leisure, between freedom and security, between love and power, between color and form, or between better and worse. Value, in the sense of what we have to give up of one thing in order to get a unit of another—i.e., as a "transformation ratio"—is a phenomenon we meet in every conceivable branch

* Napoleon complex

of human activity, for wherever there is limitation, wherever there is choice, wherever we cannot have our cake and eat it, there the value phenomenon pops up. The novelist balancing up his chapters, the painter balancing his picture, the general apportioning his troops, the preacher arranging his service, the professor preparing his course, the cook planning a menu, the government formulating a policy, are all of them facing essentially the same "economic" problem as in the apportionment of time or the spending of money. Wherever resources are limited, choice is necessary and value raises its earthy head. It may be, as Wordsworth says, that "High Heaven rejects the lore of nicely calculated less or more" (i.e., economics), but, even if this is the case (and Wordsworth's authority is by no means unimpeachable), it is merely because High Heaven is presumably possessed of unlimited resources. In some fields the "less or more" may be less nicely calculated than in the market place, though one sometimes wonders after studying the exotic behavior of banks, corporations, and labor unions whether these phenomena could not be profitably studied with the techniques of the cultural anthropologist. Custom, habit, tradition, and ritual play an important part in the day-to-day activity of the most solemnly economic and ostensibly money-making institution. On the other hand, the balancing of advantage against disadvantage which is the mark of the "economizing" process is found among the most primitive tribes, the most careless bohemians and the most otherworldly saints. Indeed, it may well be that the saint—who knows what spiritual goods he wants and who goes after them regardless of how many norms of conventional behavior he shatters—is closer to the pattern of economic man than is the frock-coated banker whose watchword is respectability (a thoroughly primitive, anthropological concept) and whose walk of life is hedged about with innumerable barriers of established custom.

Economics is significant, then, not merely because it investigates an important slice of life in the market place, but because the phenomena which emerge in a relatively clear and quantitative form in the market place are also found in virtually all other human activities. Hence, economic life itself, in the narrow sense of that part of human activity that is concerned with buying, selling, producing, and consuming, is a "model" of the whole vast complex of human activity and experience, and the principles which are discovered in a clear and quantitative form in the market may be applied to the understanding of apparently quite unrelated phenomena in biology, art, religion, morals, politics, and the whole complex structure of human relationships. I do not mean, of course, that economic principles are *sufficient* to the understanding of the complex universe of reality; but they are, I believe, a necessary implement in the inquirer's tool chest.

It is also true, of course, that principles which come to the clearest expression in the study of other subject matters are of great importance in the interpretation of so-called "economic" phenomena. The concept of an ecological system, which was developed first in the biological sciences —i.e., of a system of populations of various things, in which the equilibrium size and the movement of each population are dependent on the size of other populations—is an interpretive principle of the utmost value in the social sciences. Just as a pond develops an equilibrium population of frogs, fishes, bacteria, algae, and the like, all in subtle competitive and cooperative relationships with one another, so society is a great pond, developing equilibrium populations of Baptist churches, post offices, gas stations, families, counties, states, wheat farmers, chickens, and so on, which also exhibit complex cooperative and competitive relations one with another. The concept of mechanical equilibrium, both static and dynamic, has also had an immense impact—indeed, too great an impact—on the social sciences. Wherever we find a potential difference producing a current or flow by overcoming a resistance, we find something like Ohm's law, exhibited in its purest form in the study of electricity, but valuable as an interpretive principle when we study the flow of goods or of resources in response to price differences (economic potential) against the resistance imposed by costs of transport. In the theory of electrical circuits we may find clues to some baffling phenomena connected with the circuit flow of money.

Within the social sciences themselves, concepts which have been developed in anthropology, such as systems of ritualistic and customary behavior, and concepts which have been developed in sociology and social psychology, such as the crisis-adjustment patterns in family relationships, are all applicable to the subject matter of economics.

Indeed, I see the great empire of human knowledge, not as a conglomeration of independent and perhaps even warring kingdoms, each cultivating its own little field of subject matter by its own methods and each living wholly on its own produce, but as a great Republic of the mind, comprised, it is true, of subdivisions such as

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Physics, Chemistry, Economics, Botany, and the like, the boundaries of which are, like the boundaries of political states, partly the result of historic accident and partly the result of the lay of the land, but all uniting and cooperating in a common task of producing and exchanging the most precious of all commodities, and, indeed, exchanging not only the results of their labors, but exchanging also the tools which the special requirements of each field have perfected.

II

I propose to devote the remainder of this article, therefore, to a brief discussion of the contribution which the methods of economics may be able to make to other fields.

Recent developments in economics in the theory of oligopoly have an important bearing on problems of political science. It is perhaps significant that there was no representative from political science in this symposium. In a day when civilization itself is threatened by our inability to solve an essentially political problem (the abolition of war), it is tragic that so little fundamental thinking is being done in political science. Even the World Federalists—the only group who seem to be intellectually active in this field at all—seem to have got little further than the eighteenth century. It may well be that a significant revival in political thought will come out of the economics of oligopoly, where we are concerned essentially with problems of *strategy*—i.e., situations in which the choices of each person or organization involved depend upon their expectations regarding the choices of the others. It may be that the present bankruptcy of the national state, which can provide us with neither security, justice, peace, nor honor, is closely associated with the duopolistic character of international rivalry. There are marked similarities between the power struggles of oligopolistic firms and the power struggles of states: price wars and sales wars exhibit in a simplified form many of the essential problems of that most detestable of sciences, military science. There is no more striking contrast than between the resourcefulness and inventiveness which is shown in dealing with the "war" problem in the business world, with its multitudinous forms of agreement and federation, and the sterility and ritualistic rigidity of the political world.

Economics can also make an important contribution to those sciences in which general equilibria or a great multiplicity of interconnected relationships are characteristic of the subject matter. In economics, as in astronomy, the experimental method is almost impossible. We cannot simplify our universe, as the chemist or the physicist does, by the artificial creation of conditions in which virtually all factors but the ones we are investigating are excluded. We cannot take a businessman or a household and expose them first to one set of prices and then to another set to see what happens. Our subject matter is presented to us in a manner that is for the most part not within our control; there is no recipe for unscrambling in fact the magnificent omelette of social experience. We are always faced with an overwhelming and baffling multiplicity, and because of the very dominance of the problem we have been forced to devise methods for handling it.

These methods fall into three groups. There is first the *ceteris paribus* approach, identified mainly with the name of Marshall, which is in a sense a method of intellectual experiment, involving the isolation of a single problem by the assumption that all variables other than those investigated are held constant. This method has yielded valuable results in a limited sphere, and is a necessary prerequisite to the solution of more difficult problems. Nevertheless, it also has its dangers, especially the danger of overgeneralization from the particular to the general case. Thus the fact that a fall in the wages of carpenters is likely to lead to a rise in the amount of employment offered to them by no means implies that the remedy for general unemployment is general wage reduction. It is easy to fall into fallacies of composition when using this method, but in spite of its dangers it remains a necessary implement in the economist's, and indeed in any scientist's, tool bag.

The second method is one that is familiar in the physical sciences, the method of simultaneous equations. In economics this is associated chiefly with the name of Leon Walras and the Lausanne school. It is based on the proposition that any system of n variables, each of which can be written as a function of all the others, yields n of these equations which may be capable of solution to yield values of the variables each of which is consistent with every other. The difficulty of the method is that unless we know a good deal about the form of the assumed functional relationships we cannot be positive that the system has a "real" solution, or that it does not have many real solutions. It may even have solutions that are mathematically correct but economically meaningless, such as negative prices. Consequently, if we except the pioneering work of Leontieff at Harvard, the

method has not been particularly fruitful of results in economics, in spite of its superior elegance and generality.

The third method is that associated with the name of Keynes, now frequently called that of "macroeconomics." This consists essentially in using large aggregates of economic variables as the basic parameters of simplified models, the exact properties of which can be fairly easily determined. In a sense this combines the simplicity and fruitfulness of the Marshallian approach with the generality of the Walrasian. Marshall's method is admirable in discussing the forces that determine the price and output of, say, limburger cheese, but it cannot deal with the problems of the system as a whole. Walras deals with the system as a whole, but at such a level of generality and abstraction that practically nothing can be said about it except that it exists. Keynes, by taking the system as a whole, but ruthlessly lumping it into large aggregates, the relationships of which he explores, effects in a sense a combination of the virtues of both the other methods. The macroeconomic models are simple enough to be handled, and yet cover the whole system. Not that the macroeconomic method is without its own dangers. Aggregates like "the national income," or "the level of employment," or "the price level" are all heterogeneous conglomerations, and there is danger, particularly for the more mathematical and less philosophical users of the technique, of neglecting the *structure* of these aggregates. It is fatally easy to write "Let the National Income be Y and the Price Level be P" and straightway to get so deliciously involved in the manipulation of our Y s and P s that we forget that they are not simple aggregates but have a complex structure which may well be relevant to the problem in hand. This "fallacy of aggregation" is a common one; it is at the root of most of the fallacies of Marxism, with its assumption of homogeneous classes; of Nationalism, with its assumption of homogeneous nations; and it even accounts for the spectacular lack of prophetic success among the brighter young economists. Nevertheless, for all its dangers, the macroeconomic method has led to a revolution in economic thought, the end of which is by no means visible, and it creates a discipline and habit of mind which might easily create revolutions in other sciences as well. I suspect that the natural scientists are also subject to both the fallacy of composition and the fallacy of aggregation; that they are much too uncritical of their basic taxonomic systems, much too prone to generalize on the basis of particular experience, and too little sensitive to the abominable interrelatedness of things! It would be a valuable experience for any scientist to familiarize himself thoroughly with what may be called the "macroeconomic paradoxes"—the propositions which are true in individual experience but which are quite untrue for society as a whole. Thus an individual can increase his money stock by "hoarding"—i.e., spending less money than he receives: but the attempt on the part of all individuals to hoard does not result in general "hoarding;" it merely decreases the total volume of money payments. An individual can get rid of money by spending it: a society cannot. For an individual, expenditure and receipts are two very different things: for society they are exactly the same thing, every expenditure being another person's receipt. An individual can "save"—i.e., increase his net worth—by not consuming as much as his income. If everyone tries to do this the result may not be an increase in society's capital but a decline in income and employment. In distribution these paradoxes abound. A trade union may raise the wages of its members: it is very doubtful whether trade unions as a whole can raise wages as a share of the total income. Profits are determined by the level of investment, not by the wage bargain; the more business distributes in dividends, the greater will be the profits out of which dividends can be paid. The macroeconomic world is a Wonderland full of widow's cruses and Danaïd jars, where nothing is what it seems, where things do not add up, where the collective result of individual decisions is something totally different from the sum of these decisions. Moreover, this is the real world: yet it cannot be understood by any generalization from individual experience; it can only be understood through the kind of intellectual discipline which economics provides. Moreover, it is not only in economics that this topsy-turviness prevails. In politics prohibition leads to drunkenness, the quest for national security leads to national destruction, the more literate we make people the less educated they become, and the conquest of nature by the physical sciences leads to ever-increasing misery, fear, and degradation.

III

I have not attempted in this paper to defend economics by reference to the importance of its subject matter, as that can hardly be a matter of question. Was Marx right in supposing that capitalism has an inherent contradiction in it? What

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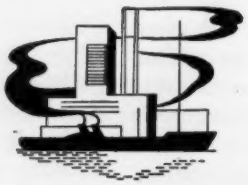
is the necessary minimum of governmental intervention into economic life? Can inflations and depressions be remedied? How far can the distribution of income be equalized without destroying the roots of economic progress? These and like questions cannot possibly be answered without serious study, and the name of this serious study is economics. One needs no more reminder of its necessity. It is trite, but frighteningly true, to say that the survival of this present civilization depends, not on the further development of natural science, but on the solution of certain serious intellectual problems in the social sciences.

In conclusion, I should like to urge the necessity for the study of economics not only for its conclusions and methods, but also for the state of mind it produces. In the old Cambridge tripos, economics—or, to give it its grander title, political economy—was listed as a Moral Science. For all the attempts of our positivists to dehumanize the sciences of man, a moral science it remains. Its central problem is the problem of value: and value is but a step from virtue. Every science, like every craft, imposes certain of its marks on its practitioners. I would hesitate to suggest, especially to members of the AAAS, that geologists grow like their rocks, chemists like their smells, or even astronomers like their heavens. I cannot forbear, however, from quoting from Professor Robbins, of the London School of Economics: "It is not an exaggeration to say that, at the present day, one of the main dangers to civilisation arises from the inability of minds trained in the natural sciences to perceive the difference between the economic and the technical." In the lurid twilight of science in which we live, when it has gained the whole world and lost its own soul, when it is everywhere prostituted to special interests, whether of the dairy farmers, the steel industry, or the national state, when the search for truth is subordinated to the lust for power, it is not altogether an accident that it is in the social science departments that the occasional voice crying in the wilderness is most likely to be heard. In a world of technicians, it is the economist who raises the cry that the technically most efficient in not necessarily, or even usually, the socially most efficient; that the best cow is not the one that gives the most milk; the best business is not the one that makes the most profits; the best army is not the one that creates the most havoc; and, above all, that the best training is not the best education. In a day when self-interest, nationalism, totalitarianism, militarism, and a dreadful pride threaten our very existence, economics points always toward the general interest, looks toward a free-trading world society, claims that the business of living even in a complex society can be accomplished with a small minimum of police coercion, urges that plenty is the source of power and war the greatest enemy of plenty, and by its very failures induces that humility for lack of which we perish.



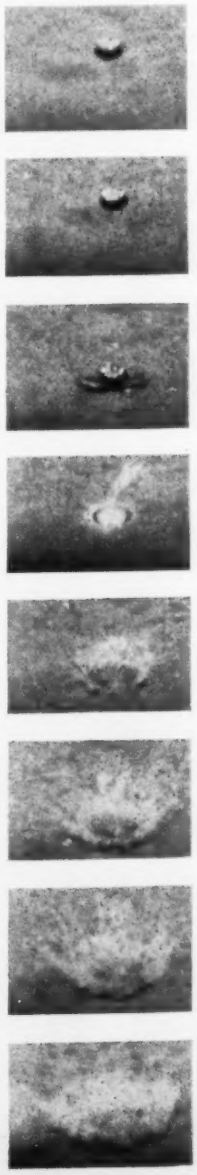
PROTECTING THE LAND AGAINST THE RAINDROP'S BLAST

W. D. ELLISON

Mr. Ellison is a graduate of the School of Engineering, Montana State College, and has been engaged in hydrologic and soils research for more than twenty years, mostly with the USDA. While director of the North Appalachian Hydrologic Research Station he developed a new type of water-cycle lysimeter that would weigh a 120,000-block of field soil with such accuracy that one could detect the collection of a heavy evening dew on its surface, and the water given off by plant transpiration during the day. Mr. Ellison is now Soil Conservationist in the U. S. Navy.

EACH falling raindrop that strikes the ground acts as a miniature bomb and splashes soil into the air at its point of impact. Violent rainstorms have great capacity to splash the soil and to damage the land by this "blasting" action. Measurements made by new methods have disclosed wide differences in the destructive action of raindrops that fall in different types of storms. They have also divulged some new facts about the soil and have shown that different soils are destroyed in different ways, and at different rates, by the impact and splash of falling raindrops. These new data indicate that the amount of vegetal cover protection needed to conserve the soil will vary with these differences in rainfall and soil characteristics. Rainfall characteristics are known to vary from one climatic region to another, and from season to season within each region; and soils may vary from one field to another, and even from one acre to another on a single field.

Such variations point to an important need for measuring impact characteristics of storms, and resistance characteristics (stability factors) of soils, before attempting to fit a cropping practice to the land. Some of the wide differences in the factors of rainfall, soil, and protective cover are indicated by a limited number of measurements made during the past year. The results show that differences in drop impacts, from one storm to another, may cause the soil splash on a bare field to vary from less than 1 ton per acre to more than 100 tons per acre; that differences in soil characteristics may vary the splash by more than 450 percent; and that differences in the protective values of vegetal covers may cause the soil splash to vary by more than 10,000 percent. Such latitude in the controlling factors provides wide opportunity for setting up some new cropping practices; practices that are tailor-made to protect each field according to the soil's protective requirements.



Falling raindrop coming in contact with soil. Shots taken 1/1000 second apart show its splashing effects.

Soil splash by raindrop impact represents a form of soil erosion that may be called splash erosion, and it represents the very beginning of erosion on land surfaces outside the gullies and channels. It sets in motion a chain of destructive events that are of outstanding importance because of their harmful effects on the land. Unfortunately, we have not been charging splash damage to the effects of raindrops. The splashes are much too fast for the unaided eye to detect, and, being unaware of their presence, we have generally attributed their harmful results to the erosive action of flowing surface water. It is true that surface flow often plays a very important role in this whole chain of destruction; but the surface flow, when acting alone, without the antecedent effects of raindrop splashes would be relatively ineffective on the fields where the flow is not channelized.

There have also been attempts to indict the moldboard plow for the damage caused by splashing raindrops. Obviously, the use of the plow has often

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been so badly mismanaged that it has accelerated splash erosion, but many other things have also been mismanaged in ways that multiplied splash damage. For example, milch cows have been allowed to overgraze pastures and meadows to an extent that splash erosion became active and caused the soils to decline to less than 10 percent of full productivity. Solutions to the problems posed should be found in a study of the erosion process and in the development of management practices for the control of splash hazards. In the case of overgrazing, of course, the grazing cows need not be eliminated, and the same reasoning applies in the case of the moldboard plow. Perhaps the plow, too, should stay with us, but under improved management practices that provide for the control of splash erosion hazards.

Many types of damage to the land and soil are associated with, and proportional to, these hazards. Such damages are so numerous and complex that nothing more than a brief description of the principal types can be given here.

One harmful effect of splashes is to accelerate the loss of topsoil over the entire surface of a field. The splash process sets topsoil in motion and also places it in suspension in the surface water. This water is kept in a turbulent state (such that it continues to suspend much of the splashed soil) by subsequent drop impacts. If these subsequent impacts were eliminated, on field surfaces outside the gullies, the soil that is first splashed into suspension would soon be deposited out of the surface water. Thus, the effects of drop impacts are largely responsible for erosion outside the gullies; erosion that scalps crests of slopes of all their topsoils and often piles and buries much of this topsoil low on a hillside.

Even a considerable part of the gulley carving that is caused by flowing surface water should be charged to splash erosion. Active splash erosion may greatly increase the runoff and also tend to make the runoff highly abrasive. This increased flow containing highly abrasive materials will carve many gullies where gullies would not otherwise be formed.

The splash erosion process puddles surface soils and causes surface seals to be formed. Often these seals will practically waterproof the land and cause most of the rainfall to run off. This increased runoff tends to increase both frequency and intensity of floods and droughts. The high temperatures associated with droughty soils in midsummer may cause baking and cracking in the clays. Surface sealing may also cause poor soil aeration; it may destroy worm life and interfere with microbial action within a soil; and may impair the land's productive capacity in other ways.

Splash erosion may result in elutriation, or a washing out and floating away of the light organic

Soil set in motion high on the slopes is piled and buried low on the hillside. This hillside is not gullied, but all the topsoil has been moved downslope and piled six feet deep near the base of the slope.

Very permeable soil with a high infiltration capacity before bare surface was exposed to 20 minutes of rainfall. Note that surface has been practically waterproofed.

materials and the fine clay factions. If the soil contains many coarse sand grains, these may be deposited out of the flow and left on the surface of the field. When this happens the runoff carries with it the very life of the land, leaving behind a topsoil that contains only sterile sand. This process tends to deplete both the fertility and the water-holding capacity of sandy fields.

All the various types of damage described above will tend to produce soil structure decline. When the broken aggregates and the puddled surface materials are incorporated into the plow layer, they make this part of the profile less permeable. Loss of organic materials in the elutriation process may also impair a soil's structural properties. Each type of damage should serve as a warning that splash erosion is active on the land.

Soil pedestals on the surface are made by the splash process, and they, too, serve to warn us of actual splash erosion on a field. These are formed under small stones, and where stems of plants, leaves, or other nonerodible objects lie fixed on the surface. These objects protect the material under them from splash by raindrop impact, whereas soil all about them may be splashed and transported away. These pedestals have been formed by splash erosion in many experimental tests, but never by surface flow. This fact is of especial interest because of published statements to the contrary, statements that have developed some popular misconceptions.

In experiments conducted by the Navy, splash action that erodes the soil was photographed with Navy cameras, using a single drop of 5.7-mm diameter. This drop was released from a height of 32 feet, and at the point of impact its velocity was approximately 32 feet per second. The capacity of this drop to cause soil splash is only slightly less than that of a raindrop of like size that falls on an open field during a quiet spring shower, but it may be less than one fourth as effective as a raindrop of like size that is driven into the soil by the high winds of a beating rainstorm.

Splash erosion science is a very new development, but already it has divulged facts that give us leads for improving many of our erosion-control techniques. Results have also shown up deficiencies in some of our experimental findings, especially those findings in which there has been no accounting for differences in the splash factors: the factors of drop impact, soil capacity to withstand such impact, and the protective value of the vegetal cover. Without measuring these basic factors, a comprehensive study of important cause-and-effect relationships in erosional damage has been impossible. Perhaps our failure to account for differences in these primary factors is the underlying reason why many of the present-day conservation practices still have to be based more on trial-and-error developments in actual field operations than on experimental findings in research programs.

The procedures and techniques employed in this new science have been developed by the author over the past twelve years, but they were first

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Above: Splashing raindrops with about 70 percent vegetal cover. *Below*: Denuded area where cap rocks protect small pedestals of soil against raindrop action.

tried out on practical field problems in 1948. Sponsored by the regional office of the Soil Conservation Service, Ft. Worth, Texas, the tests were made on rangelands at the Amarillo Experiment Station. The object of these tests on rangelands was to determine how much of the range cover can be removed by grazing at each season of the year without impairing the soil- and water-conserving functions. Results of this work were so highly promising that plans have since been completed for continuing this operation and extending it over the entire state. These same types of measurement are needed to determine minimum cover requirements on the cornfields of Iowa, the wheat fields of Kansas, the potato fields of Maine, the citrus orchards of California, and the cottonfields of Mississippi. Such determinations are basic requirements for developing the soil-protection phases of farm and range management programs everywhere.

For the purposes of this discussion soil erosion will be defined as a process of detachment and transportation of soil materials by erosive agents. This definition describes the erosion process as being comprised of two sequential happenings: detachment—a tearing loose of transportable particles from their moorings in the surface of a soil mass; and transportation of these detached materials. This definition provides no specification as to the destination of materials that are transported. It does not preclude the possibility of soil being transported to and fro on the field, and of its being finally deposited in the vicinity of its initial location. In that case there would be soil erosion without any appreciable net loss of soil from any point. A considerable amount of this type of erosion often takes place, especially by the splash process, on gentle slopes. But even though the tonnage loss of soil is inappreciable, the erosional damage can be great. The soil can lose important clay fractions, fertility elements, and organic materials, and its physical properties may be impaired in the process of being eroded. The extent of these erosional damages will depend upon the two primary erosion hazards—detachment and transportation. Where there is no appreciable soil loss, the detachment process, not the transportation, will be most destructive of the soil.

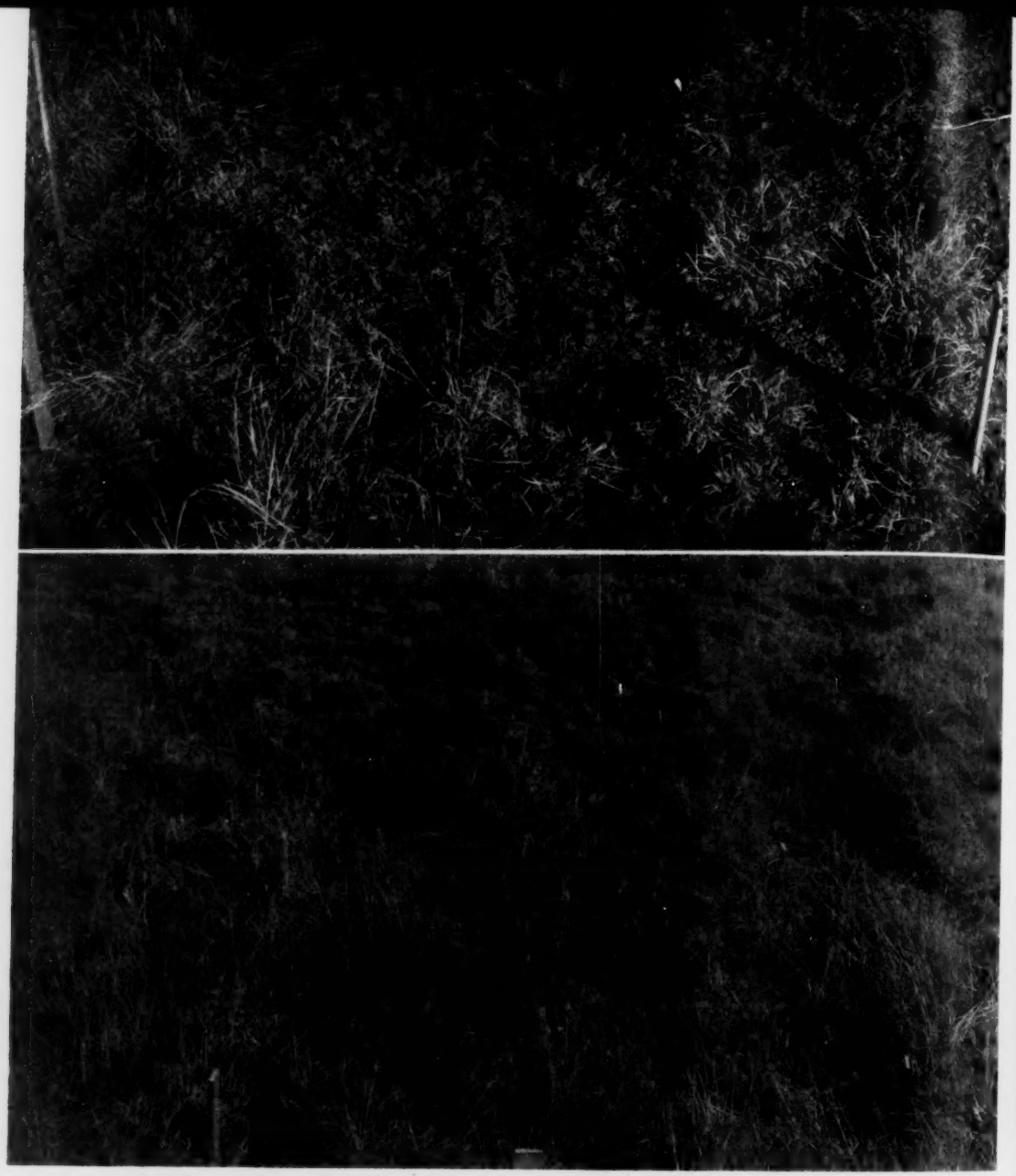
Most of the soil damage previously described as structure decline, surface sealing, elutriation, and to some extent the loss of topsoil from field slopes—and even the increases in abrasive characteristics of surface flow which cause the runoff to carve gullies—may have its beginning in soil detachment by raindrop impact. It is important, therefore, that we measure this detachment and determine its sensitivity to variations in the de-

Surface of a bare sandy soil after a fairly heavy rain. Organic materials and clay fractions have been splashed and transported from the field. The less transportable sand fractions remain and will eventually be incorporated into the plow layer.

taching capacity of falling raindrops, the detachability of the soil, and the protective value of the vegetal cover. After this has been accomplished we should be well prepared to match an effective cover management program to the protective requirements of a soil.

The detaching capacity of falling raindrops may be designated by the symbol D_3. It is measured by exposing a small standardized dish of a standard sand to the impact and splash of falling raindrops. As the drops fall and splash the sand from the dish, the detachability is assumed to be 1.0 and one unit of detaching capacity will splash one unit weight (1 gram) of sand from the dish. To determine the weight loss, the dish of sand is ovendried and weighed both before and after exposure to rainfall. The D_3 factor is then equal to the total grams of standard sand splashed out of the standardized dish during the period of rainfall.

If a rainfall having a detaching capacity of 10 (i.e., it will splash 10 grams of standard sand out of a splash dish) splashes only 6 grams of a particular soil, then the detachability factor D_2—the



Above: Poor range cover, with protective value of only 2.1. *Below*: Good range cover gives a protective value of 131.

amount of soil splashed divided by the detaching capacity of the falling raindrops—is equal to 6/10 = 0.60.

It becomes obvious that the total soil loss from a splash dish is equal to the product of soil detachability and raindrop detaching capacity. This quantity we designate by the symbol D_1. This is the detachment hazard, and it can be determined for a condition of bare soil by the formula $D_1 = D_2 \times D_3$. In this case the D_1 factor (the detachment hazard) will be expressed in terms of grams of soil splashed from the standardized dish. The dish is so small that it is assumed that all the soil detached is splashed into the air and lost from the dish. Since one gram of soil on the surface of the dish is equivalent to 0.71 tons of soil on one acre of land, the D_1 factor can be converted to tons per acre by multiplication ($D_2 \times D_3 \times 0.71$).

A vegetal cover reduces the detachment hazard by checking the impact energy of the falling raindrops and thereby reducing the effectiveness of the D_3 factor. The protective value of the cover may be designated by the symbol R, and it may be thought of as an impact-conditioning factor. If a cover reduces the effectiveness of drop impact from 100 to 50, the value of R is then 2; if the reduction is from 100 to 10, then the value of R is 10. The value of R is equal to the amount of splash that

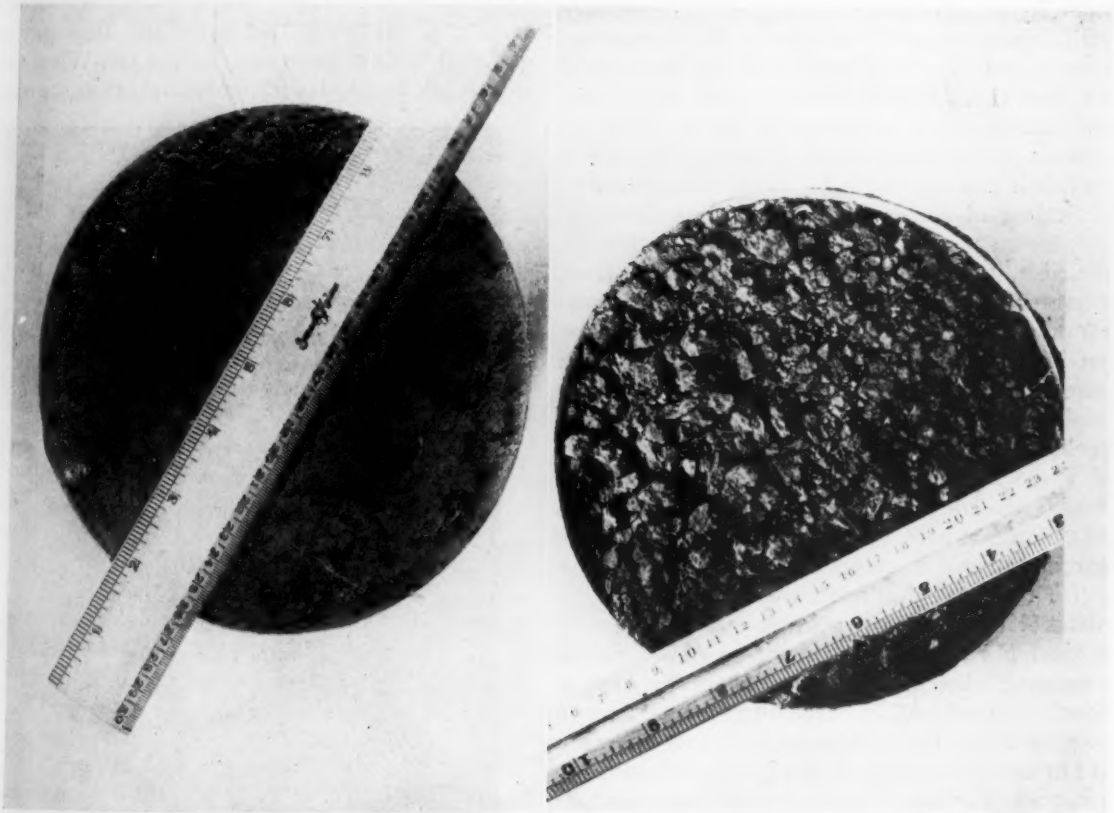
occurs without a cover, divided by the amount of splash that occurs with the cover on the soil. The formula applying to the soil with vegetal cover is $D_1 = D_2 \times D_3/R$ (multiplied by 0.71 to convert to tons per acre).

It is interesting to explore some practical applications of these techniques using results obtained in experimental studies. Detaching capacities have been measured in excess of 100 for natural rainfall, and detachability of different soils has varied from a low of 0.2 to a high of 0.9. (A greater spread in this factor is expected, perhaps reaching to a low of less than 0.1.) Protective values of cover in the range work varied from a low of 2.1 to a high of 250. To explore the effects of these variations in soils and covers, let us use a D_3 value of 100.

On soil having a D_2 value of 0.2, the detachment hazard $D_1 = 0.2 \times 100 \times 0.71 = 14.2$ tons per acre for a bare field. The R value of 2.1 was measured on a very poor range having only 704 pounds of forage and litter per acre. With this type of range the detachment hazard would be $D_1 = 0.2 \times \frac{100}{2.1} \times 0.71 = 6.8$ tons per acre. With an R value of 250 (measured on a very excellent range having 5,715 pounds of forage and litter per acre) $D_1 = 0.2 \times \frac{100}{250} \times 0.71 = 0.067$ tons per acre.

On the soil having a D_2 value of 0.9 for a bare field, the detachment hazard $D_1 = 63.9$ tons per acre. With an R value of 2.1, this hazard would be 30.4 tons per acre, and where $R = 250$, D_1 would be 0.25 ton per acre.

The magnitude of the detachment hazard that can be tolerated without causing excessive damage on the different fields and ranges will vary widely from one area to another. Controlling considerations are the types of soil damage caused; for example, where the slopes are steep, or where the soils are highly transportable, high rates of detachment are certain to result in considerable soil loss. Where the soils are sandy, high rates of detachment will cause rapid soil decline through high rates of elutriation. If the soils have relatively unstable aggregates and contain considerable clay, surface sealing may reduce water intake and lead to excessive droughtiness and to high rates of flood



Two pictures of the same soil. That on the left is from a point in the field where splash erosion has been active for a long period of years. It will be droughty, will produce high flood runoff, will be poorly aerated and difficult to farm. It will not be inhabited by sufficient worm life and will not be fully productive. That on the right has been protected against splash erosion for a long period of years and is of high quality in all respects.

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Splash dish with wick leading into ordinary fruit jar.

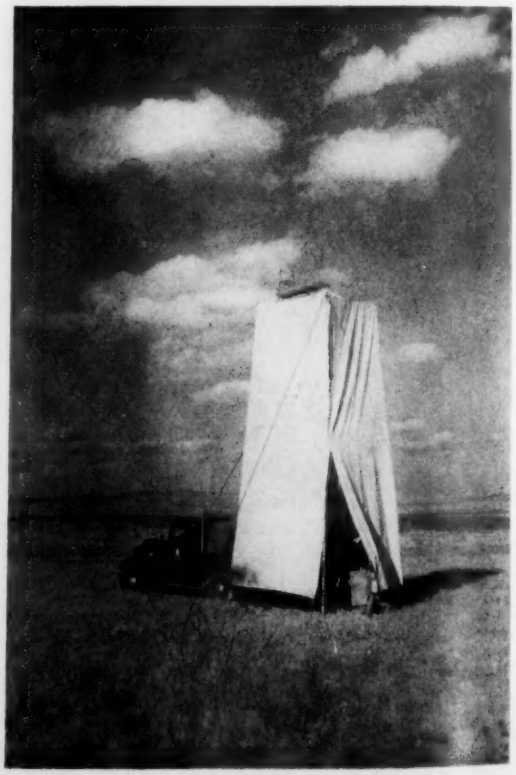
runoff. Combinations of several types of damage are certain to lead to decline of soil structure within the upper root zone. But where the land is fairly level, and the soil is neither excessively sandy nor clayey, and where the aggregates are fairly stable against breakdown by raindrops, the detachment process may not be particularly destructive. In these gently sloping areas of fairly stable soils, the detachment hazard may be permitted to increase above those tolerated on areas more subject to splash damage.

Sealing of the surface soil to an extent that soil moisture and ground-water supplies become deficient, and flood runoff becomes destructive, represents a major erosional damage that occurs on practically all soils. On one of the soils that had an infiltration rate of 0.36 inch per hour when utterly bare, the infiltration was 0.96 inch per hour under a protective cover $R = 2.1$, and it was 9.36 inches per hour under a cover $R = 250$.

These figures on water intake may be more readily understood if they are expressed in terms of gallons per acre that the soil is capable of taking through the surface layer during one hour of rainfall. The bare soil just referred to would take in only about 9,500 gallons per acre; the soil protected by a cover $R = 2.1$ would take in about 26,000 gallons per acre; whereas the soil protected by a cover $R = 250$ would take in 255,000 gallons per acre in one hour. To those dependent on ground water for industrial supplies, these figures hold great significance. To those dependent on the rain that falls (where there is no irrigation) to produce a crop, these facts should be of more than casual interest. To those who would introduce agricultural practices for the purpose of reducing flood runoffs, these facts must serve as guides for their flood-reduction programs. They indicate that a water-conservation practice for open fields should be effective before the raindrops puddle the soil and muddy the water. This puddling compacts the surface materials, and the inflow of muddy water further plugs the surface pores in about the same way that a dirty fluid might plug an ordinary kitchen strainer. When this happens the surface of the land is almost waterproofed. This curtails the benefits of rain and at the same time multiplies the damage caused by flash runoff.

The foregoing presents a brief over-all picture of splash erosion phenomena, the damage it produces, procedures and techniques employed to measure the separate factors involved, and some of the results obtained through these measuring techniques. Additional information on procedures, equipment, and techniques may be of interest.

The splash dish is 3.5 inches in diameter, 1.5 inches deep along the edges, and has a funnel-shaped bottom about 0.75 inches deep. A cloth wick prevents soil from falling through the hole in the bottom of the dish, and it overcomes surface tension of the water that percolates through the soil, and leads it down into a glass jar. When this dish is filled with standard sand and set in the open



Rainfall applicator in operation on the open range.

Turntable being loaded with splash dishes full of soil to be tested.

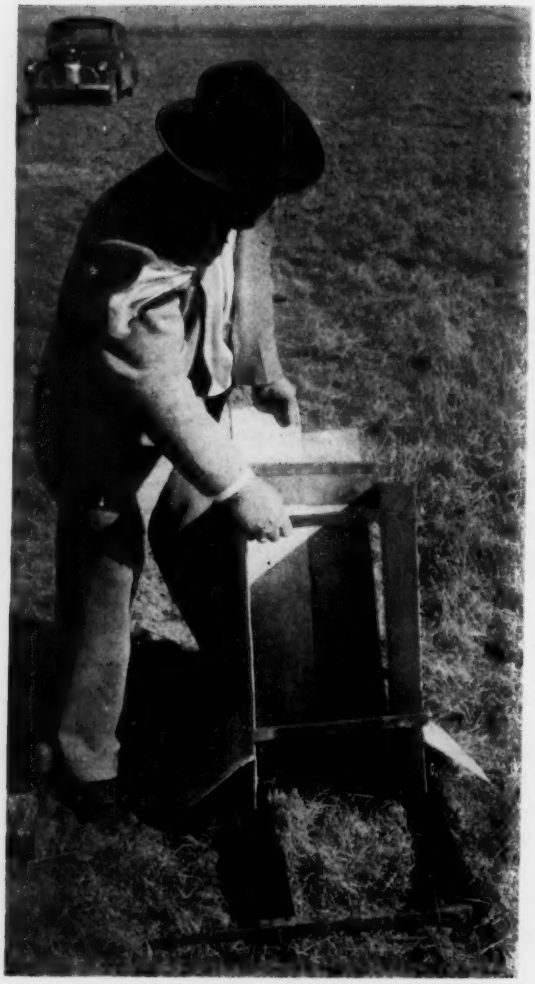
to measure the detaching capacity of natural raindrops, the glass jar is partially filled with water so that the wick carries enough moisture up into the sand to keep it wet and prevent its being blown away between periods of rainfall. The standard sand is a washed laboratory sand of 60–70-mesh size, having rounded edges.

The major piece of equipment constructed for this work is the rainfall applicator, mounted on a pickup truck to make it readily transportable. This apparatus controls each of the three variables of rainfall that affect detaching capacities. These are drop size, drop velocity, and rainfall intensity. By having control over each of these, it is an easy matter to maintain uniform rainfall with constant detaching capacity throughout a series of tests.

The water supply is carried in a pressure tank, and air pressure from a spark-plug pump drives this water up through a garden hose to a set of four spray nozzles. Suspended from the frame that holds these nozzles is a chicken-wire screen, covered with muslin. This muslin is depressed in each opening of the wire, and a yarn string about 2 inches long is run through the muslin, knotted on top, and permitted to hang from the center of each depression. The nozzles spray the water upward over this screen, and it falls back onto the muslin. Drops form as the water runs down these strings and drips off the lower ends—large drops from large strings and small drops from small strings. Only one size of yarn is used in each screen, but different screens are made up to form the different drop sizes. A 20-foot extension ladder is mounted on the back of the pickup truck so that the screen can be hoisted to any desired height. Drop velocities are controlled by the height to which the screen is hoisted and the drops are released.

Rainfall intensities are controlled by the number of nozzles used above the screen and by the amount of pressure that is developed in the pressure tank. Either two or four nozzles may be used, and operating pressures may be varied from about 20 to 30 pounds. The falling drops are protected against wind currents by a canvas curtain suspended from the top of the ladder. This equipment is used for applying raindrops when testing either the soil's detachability or the protective value of the cover on open fields and ranges.

The detachability factor should be determined for at least two different conditions of a soil. One of these will be a pulverized condition, and the other will be for a soil in field condition. For the pulverized condition, all large aggregates are removed, so that those remaining are highly transportable by the splash process (maximum sizes about 2 mm). The aggregates remaining should also be stable against breakdown by drop impact, so that for all practical purposes they act as separate particles. Under these conditions, the detachability of the soil material is controlled largely by interparticle phenomena (with aggregates acting as particles). If the particles and small aggregates are angular, so that they interlock and resist separation, the detachability tends



Splash frame. One end has been removed to show inside of apparatus.

to be lower than if they are rounded. Properties and amounts of the clays present are also important considerations.

The above-described detachability test is made with a splash dish of pulverized soil placed on a rotating table. A number of samples are set around the outer edge of the table, and it is rotated at about 5 r.p.m. As the table is turned, all the samples rotate through a common path, and this tends to smooth out and equalize the drop impacts applied to each sample. It was seldom that the amount of detachment (D_1) varied more than 5 percent between different samples of the same soil.

The test of soil in field condition can be made in either of two ways. One method is to use undisturbed cores of soil in splash dishes set on the the rotating table. When this is done the funnel-shaped bottom portion of the splash dish is filled with standard sand, and the soil core rests on top of this sand base. The surface must be free of all vegetable cover for this test. Intra-aggregate phenomena, as well as interparticle phenomena will affect the detachability of a soil in field condition.

A second method for testing detachability of a soil in the field employs a splash-frame type of sampler. This frame is set in the field so that it encloses a small plot of undisturbed, bare soil. When rainfall is applied, the splash inside this frame strikes the side walls of the sampler and flows down into small troughs, where it is preserved. The soil carried by these splashes, measured in grams, is the D_1 factor. A new D_3 factor is needed for this larger sampler. It may be obtained by setting the splash frame on a plot of the standard sand and applying rainfall. The amount of sand splashed, measured in grams, represents the D_3 value. After D_1 and D_3 have both been measured by these methods, the D_2 factor is computed from the formula $D_1 = D_2 \times D_3$.

The splash-frame type of sampler is also used to measure the protective value (R) of vegetal covers. In one method of measuring this value, standard sand is spread beneath the vegetal cover, over the surface of the soil, but inside the splash frame. In this test the amount of sand splashed by those drops not intercepted by the cover is the D_1 factor. Since the detachability of the standard sand is one (unity), the equation $D_1 = D_2 \times D_3/R$ now becomes $R = D_3/D_1$.

The other method for measuring R is based on first determining the detachability of the soil in field condition, as it is found under the vegetation. The D_1 factor is measured in a test with the splash frame, on a plot where D_2 is known. The protective value of the vegetation is then computed from the formula $R = D_2 \times D_3/D_1$.

Different sizes of frame samplers are used, but a sampler about 1.5 feet long and 0.5 foot wide will suffice for most conditions. Each time the dimensions of this frame are changed, a new D_3 value must be obtained. Each change in samplers also requires a new set of conversion factors for converting detachment hazards to units of tons per acre. All the splash within the frame is not caught with the sample, and so the sample cannot be proportioned by area factors alone. Since it is assumed that all splash on the splash dish is splashed out and can be represented by the measure of soil loss, we use this dish as a basic unit for purposes of conversion. The first step is to find what portion of the total splash in the frame is represented by the splash sample. The formula is

$$\frac{\text{(Area of frame sampler)}}{\text{(Area of dish sampler)}}$$

$$= K \frac{\text{(Splash sample caught in frame—gm)}}{\text{(soil lost from splash dish—gm)}}$$

The second step consists of proportioning the area of the splash frame and its splash sample multiplied by K to one acre. This formula is

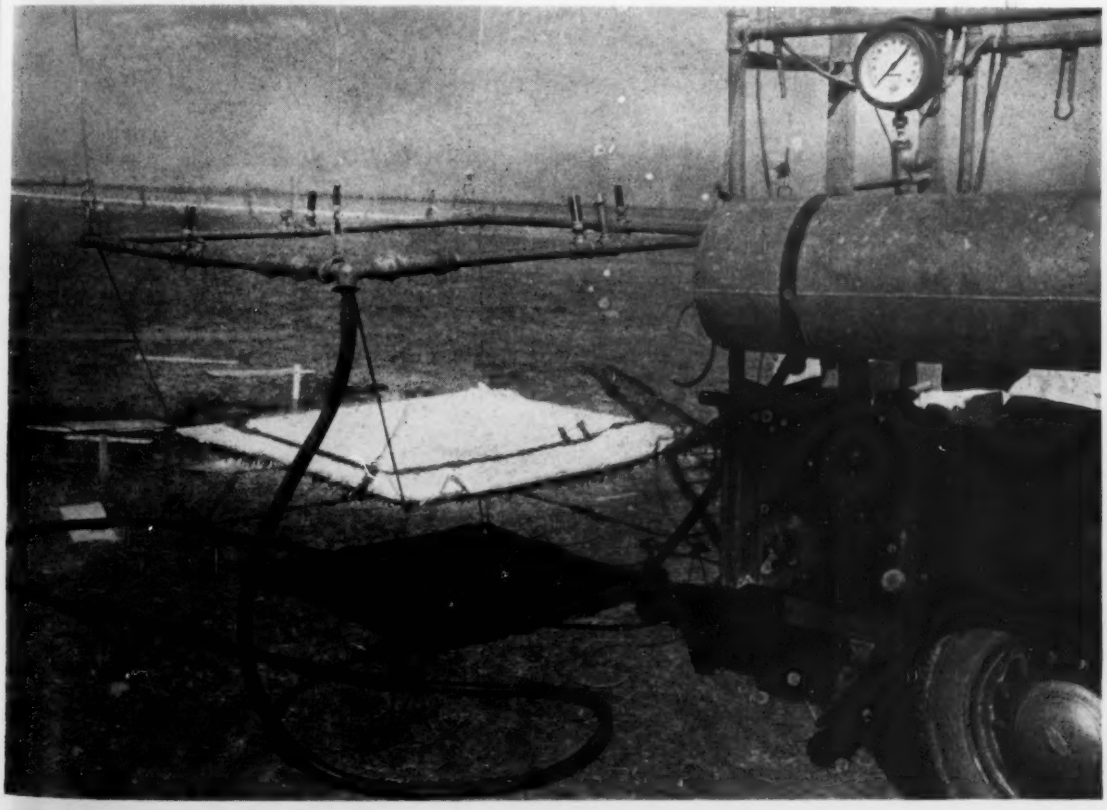
$$\frac{\text{(43,560 sq. ft. in one acre)}}{\text{(sq. ft. area of frame sampler)}} \times \frac{\text{(splash caught in frame sampler—gm)}}{453.6} \times (K) = \text{splash in pounds per acre.}$$

This work represents a new attack on problems of erosion and protection of the soil against erosional damage. It is based on a new definition of erosion, and it recognizes the impact of the raindrop as a destructive, erosive agent that must be checked before effective soil and water conservation can be achieved. So long as we blamed flowing surface water for all the erosional damage to our fields, our erosion-control practices were top-heavy with contouring operations that control only surface flow. We have talked about cover crops, but not in terms of their controlling splash erosion. Most of the cover crops used have been winter covers, which are useful in controlling leaching losses, but in matters of splash control they are usually most effective during the seasons when splash erosion is the very least. All too often the fields will be found in an unprotected condition at times when rainfall can be most destructive.

This new attack on the soil erosion problem should lead to a broad, popular recognition and appraisal of the three important factors that are so basic to the job of protecting a soil's resources. Such an appraisal is needed before we can achieve soil stability on our fields and ranges, and it may lead to the next important development in soil- and water-conservation practices.

Raindrops have always been represented to us in the role of a friend. Perhaps this fact alone has made it difficult for us to believe that they would destroy our lands. But history records many failures of entire nations whose fields were terraced but whose farmers were unaware of the invisible action of the splashing raindrops. Their terraces delayed, but they could not prevent, the inevitable destruction of their uncovered fields. Even where these terraces were constructed of massive stone, they could not possibly provide the protection their soils needed—protection against the raindrop's blast.

Photographs by the U. S. Soil Conservation Service and the U. S. Navy.



Truck with pressure tank and extension ladder mounted on rear.

GROWTH POTENTIALS OF THE HUMAN INFANT

ARNOLD GESELL

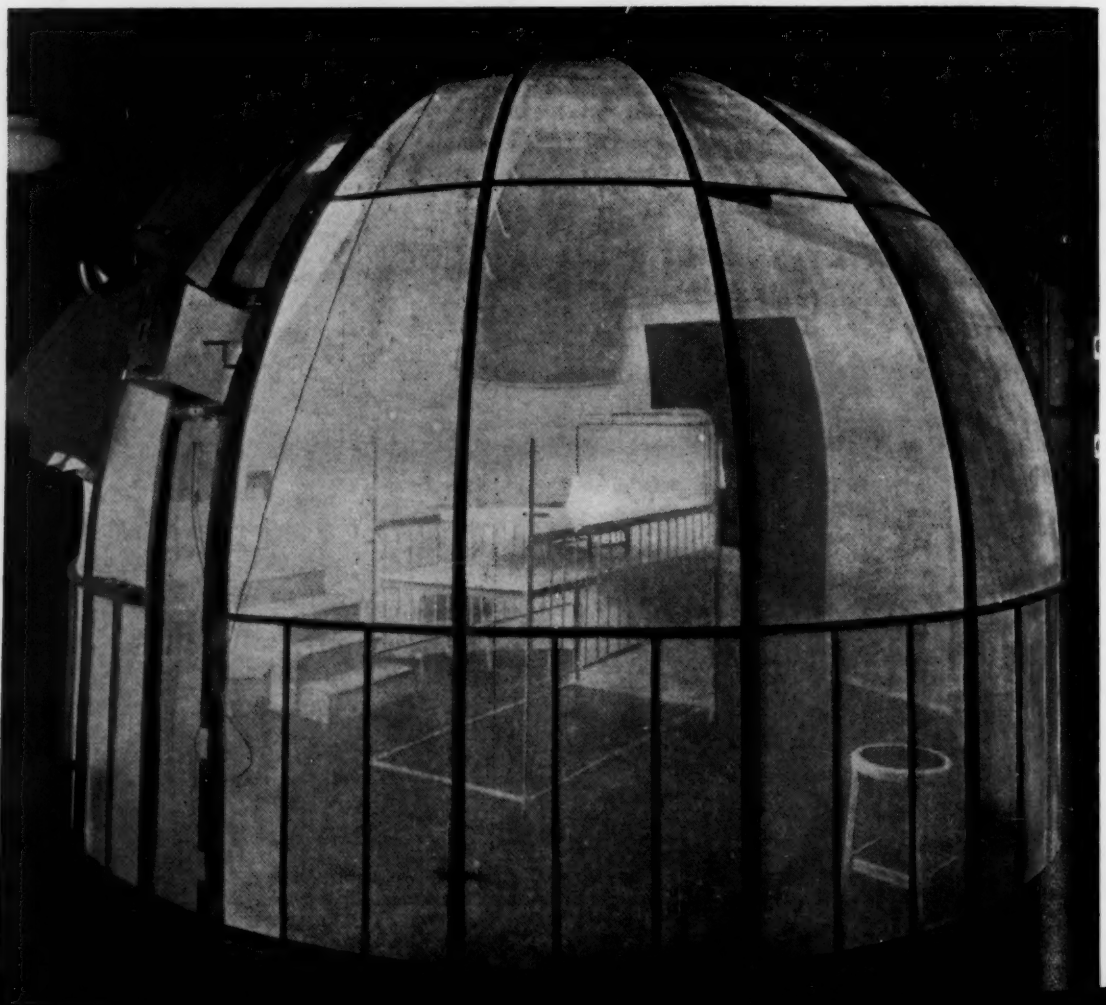
Well known for his work in developmental pediatrics, Dr. Gesell (Ph.D., Clark, 1906; M.D., Yale, 1915) is the founder of the former Clinic of Child Development at Yale University. His article is based on the address he gave in the symposium on "Educability" during the Centennial Celebration of the AAAS.

ALL educability is dependent upon innate capacities of growth. This intrinsic growth is a gift of nature. It can be guided, but it cannot be created; nor can it be transcended by any educational agency.

The problem of human educability therefore must reckon with two closely related concepts, namely, *learning* and *growth*. Darwin understood this when he suggested toward the end of his life that more accurate knowledge of the development of infants would probably give a foundation for some improvement in their education.

From the vantage point of post-Darwinian science, we begin to see each child as the focal end product of age-old processes of evolution. Biologically considered, infancy is a period of formative immaturity, which is most prolonged and most intensified in the very species which stands highest

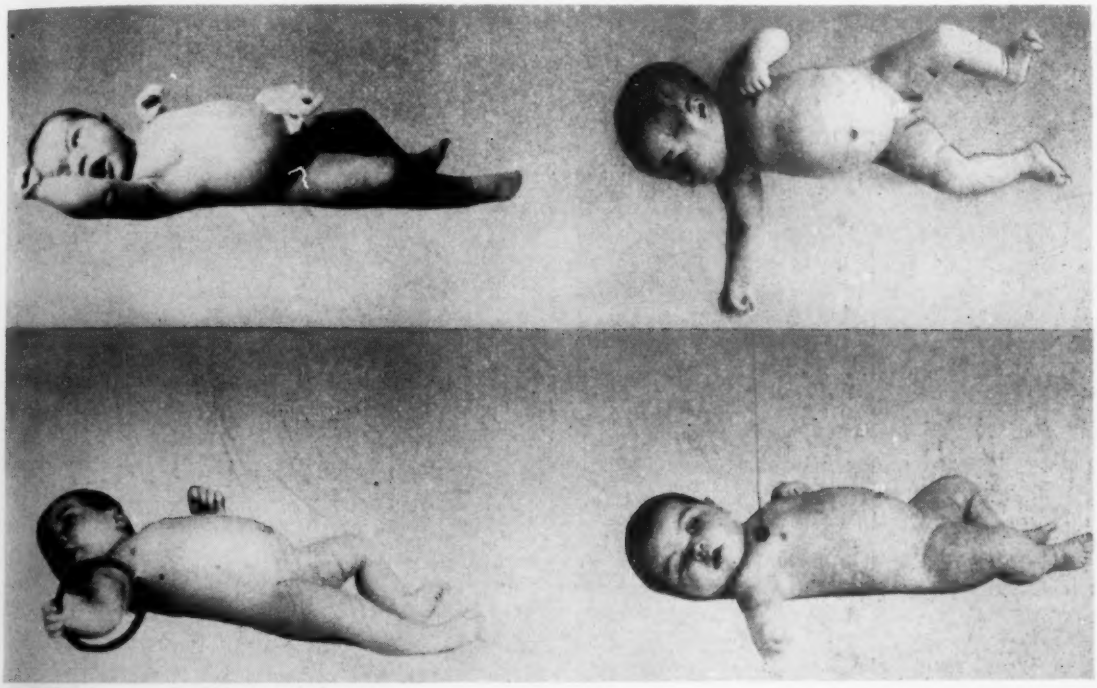
The photographic dome. This structure served both as an observatory and as a device for systematic cinema recording of the growth stages of infant behavior patterns. The interior was illuminated with Cooper-Hewitt and Mazda lamps, and two silent 16-mm cameras were mounted on the quadrants. A clinical examining crib and test materials were used to elicit behavior under standardized conditions. The dome was encased in a one-way vision screen, which effectively concealed observers and operators stationed outside.



in the life scale—presumably in our own! Bernard Shaw rather deplores this circumstance. Accordingly, in his *Metabiological Pentateuch,* he arranges matters otherwise; and on a summer afternoon in the year A.D. 31,920, the Newly Born emerges from a fabulous eggshell (some "filaments of spare albumen clinging to her here and there") —an exquisite creature endowed with speech and the full-fledged intelligence of a seventeen-year-old youth. With such a precocious start and a Back-to-Methuselah life cycle, the race may indeed be in a better position to cope with its cultural problems.

diameter. He takes hold of the world with his eyes before he does so with his hands. But at twenty-four weeks he can pick up a one-inch block on sight. His early manual grasp is pawlike, palmar and ulnar. Soon it becomes digital and radial. At forty weeks he picks up the pellet with fingertips by precise pincer prehension. At fifteen months he releases this same pellet into a bottle; he adaptively superimposes one block upon another. At eighteen months he builds a tower of three blocks; at two years, a wall; at three years, a bridge.

I rehearse this brief tale because it illustrates



The tonic neck reflex pattern exhibited in a normal infant at one week, six weeks, eight weeks, and twelve weeks of age. Eyes and hands function with increasing coordination after the third month, as shown on page 254.

The infant of today, nevertheless, is born with prodigious powers of psychological growth. Note how swiftly and progressively he gains command of his eyes and hands. Very soon after birth he is able to fixate an eye upon an object of interest; first he fixates with one eye, then with the other, later with each in rapid rhythmic alternation, and later conjointly and convergently. At four weeks he gives sustained binocular regard to an object brought into his line of vision; at eight weeks he follows it with head rotation; at twelve weeks he looks regardfully at his own hand; at sixteen weeks, when seated in a supportive chair in front of a test table, he can focus eyes upon a tiny pellet 7 mm in

what the infant himself rehearses by way of his own ontogenetic development. The significant fact about these patterns of eye-hand behavior is that they are not products of formal instruction, training, nor of education in a narrow sense. They are self-taught, self-initiated. In sequence and form they represent a generic ground plan of child development. The ground plan is primarily determined by genes. Environmental factors support, inflect, and modify, but they do not generate, the basic progressions of development. When the infant enters the world, he is already in possession of fundamental growth potentials which are distinctively his own, though phyletic in their origin.

With the aid of motion-picture cameras at the Yale Clinic, we have documented thousands of behavior patterns and pattern phases at thirty-four progressive age levels, from the period of fetal infancy through the first ten years of life. Growth gradations were charted in four major fields of behavior: motor, language, adaptive, personal-social. These objective records show that, although no two individuals are exactly alike, all normal children tend to follow a general sequence of growth characteristic of the species and of a cultural group. Every child has a unique pattern of growth, but that pattern is a variant of a basic ground plan. The species sequences are part of an established order of nature. Accordingly, the eyes take the lead, the hands follow; palmar grasp comes before digital; creeping before walking; crying before laughing; towers before walls; vertical crayon strokes before horizontal, and horizontal before oblique. First the blade, then the ear.

Growth is a step-by-step process. Each step is made possible by the step that preceded. The mind thus grows by natural stages. Maximum educability is realized only when educational measures are attuned to the maturity status of the organism. We have demonstrated the significance of maturity factors by extensive use of the method of co-twin control. One of a pair of extremely similar, single-egg twins was intensively trained for periods of six to eight weeks in a specific activity; the other twin was reserved as a comparative control. Objective data supported by cinemanalysis were gathered for stair climbing, constructive play with blocks, vocabulary training, digit and object memory, and motor skills in ring tossing and paper cutting. In none of these activities was it possible to confer a permanent advantage of skill upon either twin. After a lapse of a few weeks or months, the performances of the twins on the various tests were as similar to each other as at the beginning of the given experiment. I hasten to say that this does not prove that twins (or singletons) should not be educated. We simply have demonstrated in quantitative terms that the efficacy of training varies enormously with the developmental readiness of the infant and child.

Maturation is the net sum of gene effects operating in a self-limited life cycle. If you are reluctant to acknowledge the educational importance of genes, you may say, "This is all very well for such physical reactions as walking, stair climbing, block building, writing, drawing, and motor skills. But does it apply to emotions, to morals, to personality, and to the spiritual aspects of childhood?"

A lawful growth sequence illustrated by cube behavior patterns. Crude radial prehension at twenty-eight weeks; a wall at two years; a bridge at three years; and a gateway at four years.

Our studies show that the higher psychical manifestations of child life also are profoundly subject to laws of development. From the standpoint of development, body and mind are indivisible. The child comes by his mind as he comes by his body, through the organizing processes of growth. Psychically, he inherits nothing fully formed. Each and every part of his nature has to grow—and his sense of self, his fears, his affections and his curiosities, his feelings toward mother, father, playmates, and sex, his judgments of good and bad, of ugly and beautiful, his respect for truth and property, his sense of humor, his ideas about life and death, crime, war, nature, and deity. All his sentiments, concepts, and attitudes are products of growth and experience. For all these diverse areas of behavior it is possible to formulate gradations and gradients of growth which represent the natural maturational stages by which the child assimilates the complex culture into which he is born.

The culture also assimilates him through its "gigantic conditioning apparatus." But the process of acculturation is fundamentally delimited and pervasively patterned by the mechanisms of maturation inherent in the individual.

Educability is delimited and configured by the selfsame mechanisms; for educability does not depend upon a formless kind of plasticity. It depends upon the structured nascencies of the mind as a growing organism. The human mind is a minutely architectured action system which has an embryogenesis and a developmental morphology, manifested in patterns of behavior. The forms and lawful sequences of these patterns can be defined by scientific methods. This is the task of a genetic and clinical science of child development.

More knowledge needs to be applied at the beginnings of the life cycle to reduce the mounting tide of adolescent instability and of adult abnormalities of behavior. Through broadened methods of developmental diagnosis and supervision in infancy, through individualized growth guidance in nursery and elementary schools, we can strengthen the stamina of the child and of the family unit. We can foster basic virtues and discover distinctive gifts and talents—academic and nonacademic—in the early years of life. We cannot make democracy a genuine folkway, unless we bring into the homes of the people a *developmental philosophy*

of child care that is rooted in scientific research.

No one has to teach a baby the elements of growing. He knows all that by heart, for nature drilled it into him through countless ages of evolution. What is more, nature compounded him so ingeniously that no one just like him will ever be born again. He is an individual. Under given environmental conditions, his inborn growth potentials will govern the extent and the modes of his maturing. His growth characteristics constitute the very core of his individuality, and by the same token his educability. To rear him aright, whether at home or at school, we must understand his individuality.

He manifests this individuality from the very beginning in his natural rhythms of feeding, sleep, and self-activity. Given wisely managed opportunity he seems to know when to sleep, when to be hungry, and how much to sleep and eat. His educability is not so bland and undifferentiated that he responds neatly to an iron-clad feeding schedule. Things work out better, if his own self-regulation mechanisms, which are really growth mechanisms, are given a reasonable scope. The discerning physician makes no arbitrary distinctions between physical and mental factors; he gives conjoint consideration to the infant's nutritional status, to his immunities, allergies, and behavior traits. The child grows as a unit.

The task of the culture, likewise, is to watch for signs and symptoms of the child's total well-being with a special concern for psychological health. We must go along with the baby far enough to build up in him a sense of security. Step by step it is possible to build up his self-confidence through strengthening his confidence in his caretakers. Gradually he gains in morale and social insights, not through sheer indulgence, but through perceptive guidance on the part of his elders. And the more these elders know about the processes of growth, the more they will enjoy the truly remarkable progress which normal children make even in the first five years of life.

The intrinsic badness of children has, in my opinion, been vastly exaggerated by distorting interpretations. Well-constituted children with healthy inheritance have an intrinsic charm—a charm which betokens intrinsic goodness. The growth potentials for good far outweigh those for evil, unless the cultural odds are too heavily weighted against the child.

It is too freely said that science is indifferent to human values. I would say in this connection that science by implication is always concerned with values, and the life sciences which deal with the physiology and the pathologies of growth are coming profoundly to grips with the deepmost determiners of human values. The race evolved, the child grows. And we shall not have the requisite self-knowledge to manage our culture until we make a more sedulous effort to understand the ways of all growth and the potentials of child growth, which are the culminating evidences and products of organic evolution.

This evolution has not ceased; and to that degree man still remains educable. He seems to have reached the very acme of mass cruelty, confusion, conflict, and destructiveness. Therein lies a tithe of hope. It would seem that on sheer evolutional grounds of survival, man must and can shift to a higher cerebral plane of attitude and action. Among other things, he surely needs a science of behavior, a systematically prosecuted science, which will not only probe the lingering wickedness of old Adam, but which will explore with unrelenting penetration the rich repository of potentials for good, which are revealed with awesome mystery in the sequences of child development.

WEEDS, FUNGI, AND THE EDUCATION OF BOTANISTS

FREEMAN WEISS

Dr. Weiss (Ph.D., Cornell, 1923), who is a plant pathologist at the Bureau of Plant Industry, USDA, Beltsville, Maryland, gave the address from which his article is taken as retiring president of the Botanical Society of Washington last December 10.

THIS paper is the result partly of necessity and partly of a challenge. The necessity arises from the tradition of the Botanical Society of Washington that its president, who is effectively muzzled all year by his role of presiding officer during the Society's debates on matters botanical, is at last allowed his say at the end of his term. The challenge was perhaps unintentionally issued by one of our fellow-members and an esteemed professional colleague, L. K. Kephart, at a meeting of the Society in 1935. In the course of a review of the then recently established project on weed control of the U. S. Bureau of Plant Industry, Kephart stated that of all the agents of weed destruction or suppression that had been tested, only plant diseases had failed to be of any help whatever.

As a plant pathologist more or less nurtured in the belief that the prevention or control of plant diseases was an essential factor in our agricultural prosperity, I was amazed at the low estimate placed on their utility in combating weeds. In the meantime there has been opportunity for considerable reflection upon the subject. Granting that Kephart's conclusion was soundly based upon the available evidence in a field in which he is a specialist, the question emerges whether plant diseases are overrated (at least by pathologists) as agents of crop destruction; or are weeds endowed with special properties of disease resistance just as they have developed, through natural selection in a hostile environment, other aggressive and tenacious characters?

The possibility of embarrassment, personal or to my professional colleagues, leads me to evade answering the first part of this question, though stating my conviction that the destructive capacity of crop diseases needs no exaggeration, in a world food shortage, in order to be impressive. Perhaps another aspect of the question is whether plant pathologists have yet devised effective techniques for the mass inoculation of field-grown plants; but this is beside the present point.

There are, of course, many observations on record of damaging infections of weeds by fungus and other diseases, and there have been numerous speculations whether certain rusts and blights could be adapted to the purposeful destruction of plants. To date, however, there is little evidence that weeds, even in dense and fairly pure stands, suffer from diseases to the extent that crop plants often do; and the employment of pathogenic organisms for the extermination of weeds is still largely speculative. Indeed, in view of the rapid progress of recent years in the development of selective herbicides that destroy weeds but spare crops, the question may be of no practical consequence. The basic problem of how weeds escape or resist parasitic diseases to which crop plants, even of related species, often succumb is still vital, however. It is worthy of the serious attention of plant pathologists. Though not at all novel, this question, in both this particular aspect and also the general relations between weeds and crop diseases, has not received the attention it merits. Furthermore, the habits of weeds, as a subject essential to the liberal education of botanists, and especially of the students who will be the botanists of tomorrow, far transcend the the question of how weeds and plant diseases may interact.

The term "weed" is used here in a sense somewhat alien to the traditional concept which is, as everybody knows, "a plant out of place." In the present connection I would define a weed as a plant for which no economic use has as yet been found. It might be called an uneconomic plant. Whether in the traditional sense or the amended one proposed here, we botanists, and mayhap agriculturists as well as everyday gardeners, and also pharmacists, physicians, industrial engineers, and tycoons, have much to learn from, and about, weeds. Let us examine a few cases in point.

I

Most botanists, and also boatmen and drainage engineers who work in tropical streams, would

not question the status of the water hyacinth, *Eichhornia crassipes,* as a weed, and a most aggressive one. It is said that the progeny of a single plant can expand over some 30 acres of water surface in about 3 months. Experiments recently carried on by British technologists in India are reported to show that enough gaseous fuel, which is about 80 percent methane, can be obtained from a 30-acre crop of Eichhornia to provide cooking fuel for a thousand families for 6 months.

There are many plants, not ordinarily regarded as weeds but serving little useful purpose other than ground cover, that occupy vast areas of low-grade land useless now, and perhaps permanently, for ordinary agriculture. Examples can be found in the reeds, rushes, sedges, and grasses of tidal marshes and other areas under shallow water or subject to periodic flooding. There are also moors and uplands of great extent where the soil is too thin or the topography too rugged to permit the cultivation of ordinary crops, yet their vegetation of bracken and heather produces in the aggregate an enormous amount of plant material. Even greater in extent are the dry lands where not even the most drought-tolerant farm crops and range grasses will grow—these support a vast quantity of vegetation that has long challenged the imagination of botanists to find use for. The lush vegetation of tropical swamps and jungles still further swells the amount and variety of plant material that awaits the discovery of feasible means of utilization. If, however, water hyacinths can be economically harvested and converted into usable fuel, the prospect of similarly transforming other waste vegetation into valuable products should not appear quite hopeless.

A few years ago Ernst Berl, of the Carnegie Institute of Technology, published some rather startling claims on the feasibility of converting plant wastes into fuel oil and gasoline by a process of controlled internal combustion and hydrogenation (*Science,* 1944, **99**, 309–12). It was stated that a product that is semisolid at ordinary, but liquefiable at slightly higher, temperatures could be obtained. This "protoproduct" contains about 60 percent of the original carbon content of the plant material, has a thermal efficiency of 75 percent or higher as compared with 30 percent efficiency of coal, and by ordinary cracking processes was convertible into gasoline. Its final yield of carbon was about the same as that obtained by the conversion of carbohydrate to alcohol, but being less oxidized, its fuel value was nearly twice as great, and the conversion process was cheaper and more rapid. Berl presented some interesting calculations to show the feasibility of obtaining from ordinary crops and from plant wastes an aggregate quantity of fuel equal to the current consumption of petroleum in all forms. Thus the present sugar-cane production of four countries—Cuba, Hawaii, Puerto Rico, and the Philippine Islands—amounting to 60 million metric tons a year, would suffice, if converted into gasoline by this process, to operate about one third of the motor vehicles in the United States. Other calculations indicated that even at the lower rate of sugar-cane yield of the United States—about half that obtained in Hawaii—it would be possible to produce the amount of fuel currently obtained from petroleum here from only 5 percent of the land area now in cultivation, or from 2.3 percent of our total arable land.

These estimates are of interest in connection with some recent computations by R. M. Salter of the world's potential crop production (*Science,* 1948, **105**, 533–38). With reference to sugar production (from all sugar crops), Salter estimated that the present world total of about 30 million metric tons could be increased to nearly 180 million tons by the full utilization of all areas at present in sugar-crop production, together with the additional cultivation of all adapted tropical areas. This was estimated to be six times the world requirement for sugar provided the entire population received an adequate sugar diet. There would obviously be no purpose in producing sugar crops in such excess for food, but if other uses for sugar cane could be found of the type and on the scale proposed by Berl, the world's productive capacity might be fully utilized, to the incalculable relief of apprehension (and perhaps conflict) over its limited and dwindling petroleum resources.

The impetus thus given to the replacement of petroleum by a renewable source of energy might lead to the utilization of other plant material, less exacting than sugar cane in soil and climatic requirements, and therefore producible over a much larger part of the earth's surface. Even on a hypothetical basis, a meritorious thesis might be written by an enterprising young botanist who would calculate the area, and the productive capacity of plant material convertible into liquid or gaseous fuel, of the vast canebrakes that border many of the streams in the Southern states. The giant cane, *Arundinaria gigantea,* appears to be one of the most rapid-growing and productive of all plants, perhaps equalling sugar cane and corn in its yield of vegetable matter.

II

The foregoing has presented only quantitative aspects of utilizing waste plant material. The possibilities of recovering qualitatively useful products are equally interesting. One need only recall the phenomenal discoveries of new drugs and antibiotics within the past decade to envision possible future developments of equal importance. Some of these materials are derived from plants that previously had very limited utility. For example, rutin, a drug obtained from buckwheat, has proved so valuable in the treatment of capillary fragility in man—a major cause of paralytic stroke—that it is now estimated that some 50,000 acres of buckwheat will be needed to supply the demand for this one product. Dicoumarol, obtained from fermented sweet clover, has provided for the first time an effective remedy for coronary thrombosis. The detection of plant hormones and the study of their properties and applications have been among the most productive phases of research in plant physiology, but the possibilities of further discoveries may only have been touched. Plant pollens are among the richest sources of hormones. Corn pollen has thus far provided one of the best sources, but many plants are abundant pollen producers, as hay fever sufferers know only too well. Perhaps some of our pollen-rich but obnoxious weeds can be regenerated into useful members of the plant world when their hormone potentialities are fully explored.

Besides the familiar weeds of fields and gardens there are fungous weeds, or weed fungi, that are at least as numerous. Some of these have already been converted to the service of man. Penicillin is, of course, the best-known product to date of a fungus whose miraculous power was discovered only because it grew as a weed in a bacterial culture; but ever since its discovery the search has been urgent for other products of similar potency, not only among molds and other fungi, but also in the bacteria, algae, seed plants, and even insects. The usefulness of antibiotics in combating bacterial and other parasitic infections appears not to be limited to the diseases of man and his domestic animals. Plant diseases also may be amenable to antibiotic therapy. Penicillin itself was found to possess curative properties with respect to one of the notable diseases of plants, crown gall. Not only did it inhibit the growth of the gall-inciting bacterium in artificial cultures, but it destroyed infected cells in developed galls on plants while being harmless to normal tissues. Further tests of penicillin in relation to bacterial diseases of plants failed to establish any general antibiotic properties, although it was effective against a variety of plant pathogenic bacteria in artificial cultures. When injected into plants, either before or after inoculation with pathogenic bacteria, it exhibited little or no antibiotic effect, perhaps because of its rapid dilution by the plant sap (B. A. Rudolph. *Phytopath.*, 1946, **35**, 717–25). Nevertheless, the initial success with penicillin stimulated the search for other antibiotics that might prove useful in plant therapy. Within the last two years at least four antibiotic products of microbes, active against fungi but either nonbactericidal or only slightly so, have been reported in literature. Two of these, tentatively named "viridin" and "glutinosin" and derived from two common molds, were first described in England. To date their antibiotic properties appear to have been demonstrated only in artificial cultures, but these were exhibited against a variety of other fungi, including some that are pathogenic to plants. In the United States, two products, or perhaps one under two names, have been identified in cultures of certain actinomycetes, which are filamentous organisms showing affinities with both bacteria and fungi. These products have not only shown strong antagonistic effects against a variety of fungi—though not against the bacteria commonly used in antibiotic assays—when grown together in artificial cultures, but have proved effective as protective or curative sprays when applied to plants. The first of these was discovered by workers at the University of Wisconsin, and was reported under the name "antimycin" (C. Leben and G. W. Keitt. *Phytopath.*, 1948, **38**, 899–906). More recently, workers at Michigan State College have announced that a second antibiotic has been obtained from the actinomycete *Streptomyces griseus* (which is the source also of the bactericidal streptomycin) that has remarkable curative properties for certain mildew diseases of plants. This substance, to which the name "actidione" has been given, is said to have cured powdery mildew of beans and several similar diseases when applied as a spray in the very low concentration of 5 parts per million. As the growth of the disease agent in this instance is almost wholly on the surface of the host there is no diluting effect of the plant sap to combat. Although the demonstrated capacity to control a plant disease has thus far been limited to experimental plants grown under glass, this report is notable because of the curative ef-

fect against an already established disease and the low concentration at which the material is effective. At present, plant-disease control is largely aimed at prevention rather than cure, and the standard fungicides are used in much higher concentrations, which are often more or less directly injurious to the plants they are intended to protect.

III

It is not, however, with weeds and weed fungi as direct sources of useful products that I am principally concerned, but with the properties and mechanisms they exemplify in surviving an adverse environment, including man's vigorous efforts to eradicate them.

The familiar lawn weeds, such as plantain, dandelion, chickweed, pennywort, wild garlic, and many others, are seldom visibly affected by the vagaries of weather, and they flourish in the midst of infestations of grubs, nematodes, and other subterranean enemies that make the survival of lawn grasses all but impossible. These weeds even emerge unscathed from an attack of brown patch, caused by the omnivorous fungus parasite *Rhizoctonia*. Not only in neglected lawns, but sometimes in those on which all the science and art of plant culture have been lavished, weeds may be the only survivors. Although the crop plants of fields and gardens at times show a variety of symptoms of nutritive deficiencies, which have now been extensively catalogued, similar defects in weeds are practically unknown. Such adaptations to a rugged existence are not correlated with botanical or, more accurately, taxonomic relationships but appear more or less throughout the plant families. The city dweller who struggles to make grass grow in his yard but reaps a harvest only of weeds might suspect that the grass family is deficient in vegetative capacity and hardihood, but I have seen crab grass flourishing on a pile of builders' sand. The lily specialist who finds it difficult to preserve the health of these fair flowers throughout a single growing season might scoff at the alleged relationship of lilies to wild garlic, which thrives anywhere despite the most hostile intent of gardeners. Clearly the approach to a better understanding of the nature of weeds is not based on taxonomy, nor altogether related to the morphology of roots and seeds, although much botanical study has been expended upon these features of weeds.

The physiological approach has received less attention, yet weeds afford some remarkable examples of physiological efficiency. For example, wild garlic makes most of its growth in the late fall and early spring, when the temperature is low, the light weak, and the days short; it has only a few threadlike leaves, yet it produces an annual crop of bulbs that outweighs the photosynthetic apparatus, and it has phenomenal powers of survival through all kinds of seasons. It has notably few diseases, though it leads a self-centered life, characterized by persistent vegetative propagation and by inbreeding, both of which are said to have debilitating effects. In contrast to its tenacity of life, the suicidal disposition of the glamourized corn plant, which is said to be incapable even of survival in nature, is striking. Yet the corn plant, which thrives only in warm sunshine and long days, is considered a model of photosynthetic efficiency in the conversion of the energy of sunlight into starch. Although no plant can meet the engineer's standard of efficient conversion of energy, little is known of the capacity of weeds in this respect. Gardeners are merely sure that weeds grow faster than any useful plant.

A possible factor to explain the aggressive nature and survival capacity of weeds is their possession of properties inimical to the growth of other plants. This is a phase of plant physiology upon which there has been a great deal of speculation as well as experimental study. Space forbids more than bare mention of the efforts of physiologists to explain the often deleterious (though sometimes beneficial) influence of one kind of plant upon another, though the conclusion that such influences exist is hardly contestable. The earlier theory that ascribed such effects to excretions from the roots is now largely discredited but not wholly dead. In its place the view now prevails that this antagonism of one plant species for another, and even that between individuals of the same species, results from the post-mortem decomposition of roots and other plant parts—a process in which the microflora of the soil plays a dominant role and the rate of oxidation is a controlling factor. Much of the experimental work on this problem was done before the existence of plant hormones, and their capacity to influence plant growth in minimal concentrations, were fully recognized. It is perhaps for this reason that E. De Wildeman, a contemporary student of this phase of plant life (to which the name "allelopathy" or "teletoxy" has been given), has recently reaffirmed almost identically the conclusions stated by Pickering in the early 1900s. He holds that all plants, in whatever substrate they are found, excrete materials of various unknown chemical char-

acteristics that are injurious to their own health as well as to other plants. And he adds that "the teletoxic action of noxious weeds has not been appreciated" (*Acad. Roy. Belgique Bull. Cl. Sciences V*, 1946, 32, 117–26).

The interrelations between weeds and fungi are many and varied. Not only are weeds often the means by which fungi and other disease organisms are disseminated and enabled to survive or increase when their crop-plant hosts are inaccessible; they may also serve as the medium on which new strains of pathogenic organisms originate. The classical example of this is the production of new strains of the cereal stem-rust fungus on the barberry through the mingling of biotypes in sexual reproduction on the latter host. A similar relation doubtless holds in many other rusts that occur on economic plants, of which the diploid phase is initiated on some totally unrelated plant, often an obscure weed. Another type of weed-fungus relationship is exemplified in the part played by *Nicotiana repanda*, and other endemic species of the tobacco genus in the Southwest, in providing a permanent reservoir of inoculum of the downy-mildew fungus, which periodically spreads over the commercial tobacco culture of neighboring states to the east.

Even a casual survey of the fungus flora of the native and introduced species that are botanical relatives of crop plants shows a close parallel between their parasites, as might be expected. Moreover, it discloses many instances where the sexual, or perfect, stage of certain pleomorphic fungi, which are commonly found in only the conidial, or imperfect, stage on crop plants, is frequently encountered on their endemic botanical relatives. To young mycologists with a yen for connecting up the life cycles of pleomorphic fungi, this should be an intriguing challenge, for under the Rules of Nomenclature they can associate their own names with those legitimately applied to the perfect stages of such fungi, to the exclusion of all previous authors.

The importance of weeds, especially perennial ones, as accessory hosts of viruses that are the cause of so many important diseases of crop plants was demonstrated long ago by Doolittle and Wellman for cucumber mosaic, by Kunkel for aster yellows, by Valleau for tobacco and potato mosaic, and by many others. A more recently recognized factor that complicates the detection of such relationships, but correspondingly enhances their importance, is the existence of symptomless carriers of viruses among weeds and endemic plants. On the other hand, weeds provide students of plant viruses with some of their most useful test plants, as they seed freely, grow quickly, and sometimes exhibit very distinctive symptoms.

The occurrence of symptomless carriers of pathogenic organisms is found not alone with relation to viruses. It has been shown that certain races of the fungus *Fusarium*—a notorious agent of wilt diseases of many important crops—can be isolated from normal-appearing weeds and some field crops but are strongly pathogenic to cotton, sweet potatoes, and tomatoes. In an earlier demonstration of a similar relationship, the bacterial pathogens of tobacco wildfire and angular leaf spot were found sometimes to be present on the roots of cereals and legumes, apparently in something more than an accidental association. The bearing of these discoveries on the selection and management of crop rotations is manifest.

All these observations add up only to the conclusion that plant life must increasingly be studied as a whole. If, in the necessary initial preoccupation with plants of historic economic importance, the study of the obscure members of the plant world has been neglected, the balance must be redressed, if for no other reason than because it is easier to find out something new about the latter. There is another reason too. It has been well stated by a colleague, Dr. F. P. McWhorter, who, though he works professionally among the finest creations of floriculture, holds the highest admiration for the drab but intensely interesting plants of the desert. "The desert," he says, "is the place where life has learned to live." I would add that perhaps so also is the weed patch, not only in gardens and fields, but the microscopic weeds in the soil, the atmosphere, and even in the debris of our laboratories.

THE EVOLUTION OF THE CONCEPT OF NUMBER

F. D. MURNAGHAN

Dr. Murnaghan is a graduate of the National University of Ireland who completed his training in applied mathematics at The Johns Hopkins University (Ph.D., 1916). In 1918 he joined the Hopkins faculty and remained there until last January, when he went to Brazil to become head of the Department of Mathematics at the Centro Técnico de Aeronáutica, Rio de Janeiro. His article is from an address given before the Philosophical Society of Washington last December.

IT IS a matter of common observation that many well-educated, cultured people have a definite inferiority complex in regard to mathematics. Such persons will usually say frankly that they were good at, and enjoyed, arithmetic in their elementary schooling but that when they came to negative numbers and algebra they could not understand a word of what was going on, that as soon as they passed the course (by dint of memorizing formulas) they forgot as quickly as they could all about the matter. We feel that this attitude toward mathematics cannot be properly attributed to innate perversity, but that it is due to the fact that our teachers of mathematics do not take the time to explain properly the simple, fundamental ideas underlying the concept of number. This article is an outline of the way these ideas should, in our opinion, be presented, and we shall be amply rewarded if an occasional teacher of elementary arithmetic and algebra is tempted to incorporate some of our ideas into his teaching.

Stage 1

The counting number stage. The first stage in the concept of number is the counting number stage. The essential features of the system of counting numbers are (1) the existence of a leader, 1, and (2) the existence of a successor for each counting number, no two counting numbers having the same successor. Thus 2 is the successor of 1, 3 is the successor of 2, . . . , 9 is the successor of 8, and so on. The *existence* of a leader or beginner 1 and, equally, the *nonexistence* of an ender, or final number, of the counting number system are noteworthy features of the system. Addition of counting numbers is based on the successor concept. Thus $5+8$ is defined to be the successor of $5+7$; $5+7$ is defined to be the successor of $5+6$, and so on till we reach $5+1$, which is *defined* to be the successor of 5, i.e., 6. It is clear that $7+5$ is not, *by definition*, the same as $5+7$; the latter is the successor of $5+6$, whereas the former is the successor of $7+4$. Nevertheless, both sums are the same, and this is a general property of addition of counting numbers; if a and b are any two counting numbers, the sum $a+b$ is the same as the sum $b+a$. In technical language, addition of counting numbers is a commutative operation. Furthermore, addition of counting numbers is associative; i.e., $(a+b)+c=a+(b+c)$, and we denote the common sum by $a+b+c$.

The multiplication of counting numbers is defined in terms of the addition of counting numbers. Denoting "six times nine" by 9×6 (i.e., nine multiplied by six), we define 9×6 by the formula

$$9\times6=(9\times5)+9.$$

In words: Six times nine is, by definition, five times nine plus nine. But what is five times nine? It is, again by definition, four times nine plus nine and so on till we reach 9×1, i.e., one times nine. This we define by the statement that the leader 1 of the counting number system is *polite* in multiplication; one times nine is, by definition, nine, and, generally, the product of any counting number a by one is that counting number a. It is clear that all products of counting numbers are implicitly defined by this process, and it is equally clear that 6×9, i.e., nine times six, is not, by definition, the same as 9×6, i.e., six times nine; the latter is $(9\times5)+9$, whereas the former is $(6\times8)+6$. Nevertheless, both products are the same, and this is a general property of multiplication of counting numbers; if a and b are any two counting numbers, the product $a\times b$ is the same as the product $b\times a$. In technical language, multiplication of counting numbers is a commutative operation. Furthermore, multiplication of counting numbers is associative; i.e., $(a\times b)\times c=a\times(b\times c)$, and we denote the common product by $a\times b\times c$. If you have understood all this, it will be clear to you that the statement "two times two is four" is not a definition of "four," but rather the statement of a theorem which must be demonstrated, and I leave to you the fun of demonstrating it. If it bores you because it is too easy, substitute the following theorem:

To find the product of any two counting numbers between 5 and 10, add their excesses over 5 and multiply their defects under 10. The former figure is the ten-digit number, the latter, the unit-digit number of the product. For example, if the two numbers are 6 and 8, the excesses over 5 are 1 and 3, and the sum of these is 4; the defects under 10 are 4 and 2, and the product of these is 8. Hence (if the theorem is true) $6 \times 8 = 48$.

Since multiplication of counting numbers is defined in terms of the addition of counting numbers, it is to be expected that the two operations should be simply interrelated. The simplest and most useful expression of the close relationship between the two operations is given by the formula

$$(a+b) \times c = (a \times c) + (b \times c).$$

In words: Instead of first adding and then multiplying, we can first multiply and then add. We express this fact technically by saying that multiplication is distributive with respect to addition. It is the basic fact underlying all "long multiplications" and, to give an instance more suited to the days in which we live, underlying the design of all computing machines.

This is all that space permits me to say about the first, and most important, stage in the evolution of the concept of number. It is the stage which most people understand reasonably well, and it serves as the model for the successive stages. We shall only dignify with the name "numbers" the individual members of a collection of symbols if we are in possession of two rules of operation on these elements, which rules of operation (termed addition and multiplication) possess as many as possible of the simple features that distinguish the rules of addition of counting numbers; namely, associativity, commutativity, and the distributive property of multiplication with respect to addition. I make one remark before leaving our friends the counting numbers; although their leader 1 is polite in multiplication so that $a \times 1$ is *always* the same as a, he is not polite in addition; $a + 1$ is *never* the same as a. In fact, there is no counting number which is *ever* polite in addition; $a + b$ is never the same as a.

Stage 2

The relative number stage. Here the thing we shall call a number is an *ordered* pair of counting numbers, and we are interested merely in a relationship of "relative magnitude" of the two counting numbers. The relationship of relative magnitude that 4 bears to 7 is not the same as the relationship of relative magnitude that 7 bears to 4, and this is what we mean by the adjective "ordered." The ordered pair (4,7) is not the same as the ordered pair (7,4). If we say that we start "at" the first of the two counting numbers that we write down and end "at" the second of the two counting numbers that we write down, it is highly important at which of the two counting numbers we start and at which we end.

In the concept of relative magnitude, however, the particular counting number at which we start has no significance; the relative magnitude (5,8) is the same as the relative magnitude (4,7) or the relative magnitude (3,6) and so on. Thus we have many symbols for the *same* relative magnitude. The test by which we recognize whether two symbols (a,b), (c,d) (where a, b, c, d are any four counting numbers) are symbols for the same relative magnitude is very simple: If they check by cross addition—i.e., if $a + d = b + c$—they represent the same relative magnitude; otherwise not. Thus (1,6) and (8,13) represent the same relative magnitude because $1 + 13 = 6 + 8$. Before we can call these symbols for relative magnitudes numbers, we must define our rules of addition and multiplication, and these rules should be carefully framed so as to preserve the convenient features which characterize the addition and multiplication of counting numbers.

The rule of addition of relative magnitudes is very simple and may be phrased as follows: *Respect the comma.* Thus the sum of (a,b) and (c,d) is furnished by the formula

$$(a,b) + (c,d) = (a + c, b + d).$$

It is easy to show that the sum so defined is independent of a change in the symbols used to represent either (or both) of the relative magnitudes that are being added. It is also clear (simply because we have respected the comma) that addition of relative magnitudes defined in this way is both commutative and associative. Furthermore, it is clear that the relative magnitude (a,a), in which we start and end at the same counting number, is polite in addition, and that every relative magnitude (a,b) has a unique "close associate" or partner—namely, (b,a)—which is distinguished by the fact that the sum of any relative magnitude (a,b) and its partner (b,a) is the relative magnitude (c,c) which is polite in addition. We term the polite relative magnitude (a,a) *zero* and we term the partner (b,a) of (a,b) the *negative* of (a,b); the simple fact that the relationship between any relative magnitude and its negative is a partnership makes it clear that the negative of the negative of any relative magnitude is this original relative magnitude. Furthermore, the only

relative magnitude that is its own negative is the relative magnitude zero.

As far, then, as addition of relative magnitudes is concerned everything is satisfactory. The rule of addition is as simple as the rule of addition of counting numbers (amounting, as it does, to a mere repetition of this rule), and it possesses all the convenient features of the addition of counting numbers. We have indeed a gain in the fact of the existence of a polite relative magnitude—namely, zero—and the consequent existence of partnerships between pairs of relative magnitudes (each pair consisting of a relative magnitude and its negative). But we cannot call these relative magnitudes *numbers* until we frame a second rule of combination which plays the same role with respect to the addition of relative magnitudes as does multiplication of counting numbers with respect to the addition of counting numbers. If we were not able to frame such a multiplying rule of combination, we would term our relative magnitudes *vectors* (to emphasize that we start at a counting number and end at, after being *carried* to, a counting number). It is clear that the sum of $(1, a+1)$ and $(1, b+1)$ is $(1, a+b+1)$, and so we can use the symbol a of the counting number a (preceded, to avoid confusion, by the sign +) as a shorthand or stenographic symbol for the relative magnitude $(1, a+1)$, and then our knowledge of the addition of counting numbers furnishes us with the sum of two relative magnitudes which are such that in each of them the second counting number is greater than (i.e., follows) the first; in fact, the relation $(+a) + (+b) = +(a+b)$ is valid for the stenographic symbols. When we use this stenographic notation for relative magnitudes, we denote by $-a$ the negative $(a+1, 1)$ of $(1, a+1)$, so that our relative magnitude vectors are denoted by the symbols . . . $-3, -2, -1, 0, +1, +2$ . . . . Our relative magnitude vectors have, like the counting numbers, no ender, but, unlike them, they have also no beginner. Any relative magnitude (a,b) has the predecessor $(a+1, b)$ as well as the successor $(a, b+1)$; for example, the predecessor of $+1$ is 0, the predecessor of 0 is -1, and so on. The representation of these relative magnitude vectors by equidistant points on an indefinitely extended line is familiar to everyone, and I shall not dwell on it; I content myself with the remark that we refer to this representation by the statement that relative magnitude vectors are *one-dimensional* vectors, or *vectors on a line.*

The rule of multiplication of relative magnitudes is not as natural or easy to frame as their rule of addition. Our guiding principle is that we should like, for the sake of convenience, the product of $+a$ by $+b$ to be $+ab$; in our original nonstenographic notation, then, we would like to have $(1, a+1) \times (1, b+1) = (1, ab+1)$. The following rule achieves this aim, and we adopt it as our rule of multiplication of relative magnitudes:

$$(a,b) \times (c,d) = (ad + bc, ac + bd).$$

In words: To get the first counting number of the product, cross multiply and add, and to get the second counting number of the product, multiply the corresponding counting numbers of the two given relative magnitudes and add. It is easy to verify that this rule of multiplication possesses all the features that distinguish multiplication of counting numbers; it is commutative, associative, and distributive with respect to addition. Furthermore, the product of (a,b) by $(2,1)$, i.e., -1, is the negative (b,a) of (a,b). This is the basis for the mysterious rule of signs: "Minus times plus is minus and, although plus times plus is plus, minus times minus is not minus but plus." We are now entitled to term our relative magnitudes (which have, so far, been only vectors on a line) numbers, and we refer to them as *relative numbers.* They are also known as the integers (positive, negative, and zero). It is unfortunate that this second stage of the concept of number, the relative number concept, a stage so important for all commercial and social transactions where relative magnitudes are so much more fundamental than absolute magnitudes, is so poorly understood by so many people. A person who has once grasped the concept of relative numbers will never be guilty of the absurdity of trying to count with them; he will not worry himself with such meaningless questions as: Can I have -6 things? Can I have 0 things? He cannot have -6 things, but he can be in a situation where his competitor has six more than he has; he cannot have 0 things, but he can have the same number as his competitor.

Before leaving this second stage of the concept of number I direct your attention to the Dr. Jekyll and Mr. Hyde nature of the *level* relative number (a,a), which we term zero. Zero is polite in addition, but is a murderous bandit in multiplication. The sum of any relative number and zero is that relative number, but the product of any relative number and zero is always zero. This is a natural stumbling block for the poorly instructed student of numbers. How can two zeros be the same as one zero?

Stage 3

The rational (or slope) number concept. In order to introduce the rational (or slope) number

concept let us consider an indefinitely extended line (drawn horizontally on a plane) on which the integers (positive, negative, and zero) are represented; we term such a marked line a *scale*. We now construct a series of vertical scales whose zero points are the marks on the horizontal scale (the positive integers being marked on the upper part of each of the vertical scales) and obtain in this way a checkerboard arrangement of points on the plane. We use the symbol (a,b), where a and b are now integers, i.e., relative numbers and not counting numbers, to denote the position of the integer b on the vertical scale whose zero point is the integer a on the original horizontal scale. Thus $(+1,-3)$ is the point where the integer -3 may be found on the "+1 vertical scale," i.e., the vertical scale whose zero point coincides with the position of the integer $+1$ on the original horizontal scale. The various lines from the point (0,0) to the various points (a,b) intersect, if a is not zero, the $+1$ vertical scale in points some of which coincide with the marks on the $+1$ vertical scale. For example, the line through (2,2) will intersect the $+1$ vertical scale at the mark $+1$. Terming the line through (a,b) the "line (a,b)," it is clear that the lines (a,b) and (c,d) will coincide if, and only if, the ordered pairs of integers (a,b) and (c,d) check by cross multiplication; i.e., if, and only if, $ad = bc$. We confine our attention to those lines (a,b) which intersect the $+1$ vertical scale (i.e., we consider all lines (a,b) for which $a \neq 0$), and we say that each of these lines (a,b) defines a *slope number*, which we denote by $\frac{b}{a}$ and which we mark on the $+1$ vertical scale at the point where the line (a,b) intersects the $+1$ vertical scale. Thus, the slope number $\frac{b}{1}$ is marked at the same point on the $+1$ vertical scale as is the integer b, and the slope numbers $\frac{b}{a}$ and $\frac{d}{c}$ are the same if, and only if, they check by cross multiplication; i.e., if, and only if, $bc = ad$. In other words, the lines (a,b) and (c,d) coincide if, and only if, their slope numbers are the same. These slope numbers are familiar to you as fractions, b being the numerator and a the denominator of the fraction $\frac{b}{a}$. The fraction $\frac{1}{2}$ is the slope number $\frac{1}{2}$, and $\frac{1}{2}$ is the same as $\frac{2}{4}$ simply because $4 \times 1 = 2 \times 2$. There is no fraction whose denominator is zero (simply because there is no slope number (a,b) when $a = 0$).

Before we are really entitled to call our slope numbers or fractions *numbers*, we must frame our rules of addition and of multiplication. In contrast to the situation that confronted us when we were dealing with relative numbers or integers, it is the multiplication of slope numbers that is easy and natural, whereas their addition is relatively complicated. The rule of multiplication of slope numbers may be phrased thus: *Respect the bar.* In other words, the product of $\frac{b}{a}$ by $\frac{d}{c}$ is $\frac{bd}{ac}$. Just because we respect the bar we lose none of the simple properties which characterize multiplication of integers; multiplication of slope numbers, i.e., of fractions, is commutative and associative. Whether it is distributive with respect to addition we cannot tell until we have *defined* addition of slope numbers. Our guiding principle in framing a convenient definition of addition of slope numbers is the following: If the two points (a,b) and (c,d) happen to lie on the same vertical scale (other than the zero vertical scale), i.e., if $c = a \neq 0$, we would like the sum of $\frac{b}{a}$ and $\frac{d}{c}$ to be $\frac{b+d}{a}$. This leads to the following rule of addition of slope numbers:

$$\frac{b}{a} + \frac{d}{c} = \frac{bc + ad}{ac}.$$

In words: To obtain the numerator of the sum, cross multiply and add. To obtain the denominator of the sum, multiply the two denominators. It is easy to see that addition of slope numbers, or fractions, defined in this way, is commutative and associative, and that multiplication of slope numbers is distributive with respect to it. It is also easy to see that the *average* of any two slope numbers $\frac{b}{a}$ and $\frac{d}{c}$, i.e., the product of $\left(\frac{b}{a} + \frac{d}{c}\right)$ by $\frac{1}{2}$, is represented on the $+1$ vertical scale by a mark which lies between the marks which represent $\frac{b}{a}$ and $\frac{d}{c}$. In other words, any interval, no matter how small, of our scale contains an endless number of slope numbers.

We leave this third stage in the evolution of the concept of number, the slope number or, as it is usually called, the rational number concept, with the remark that we have now sacrificed the successor property which was such an important feature of Stage 1, the counting number concept, and of Stage 2, the relative number concept. No rational number has an immediate successor or an immediate predecessor. In particular, the rational number $\frac{0}{2}$ (which we term simply the rational

number zero) has no immediate successor and no immediate predecessor. In other words, there is no smallest positive rational number and no greatest negative rational number. Despite the fact that the rational numbers lie so densely on every part of the +1 vertical scale, they can be counted so that, in a certain sense, there are no more of them than there are counting numbers. The counting is done according to the following scheme, where we show the first ten of the rational numbers:

$$\frac{0}{+1},\ \frac{+1}{+1},\ \frac{-1}{+1},\ \frac{+1}{+2},\ \frac{-1}{+2},\ \frac{+2}{+1},\ \frac{-2}{+1},\ \frac{+1}{+3},\ \frac{-1}{+3},\ \frac{+3}{+1},\ \ldots.$$

The plan underlying the counting is simple: we place each negative rational number $\frac{-b}{a}$, where a and b are positive integers, immediately after its partner $\frac{b}{a}$ and, after starting with zero, we arrange the positive rational numbers according to the size of the integer $a+b$. The positive rational numbers are all supposed written in their lowest terms, and, if two positive rational numbers $\frac{b}{a}$ and $\frac{b'}{a'}$ are such that $a+b=a'+b'$, we write down first that one of the two numbers which has the smaller numerator.

Stage 4

The real number concept. Despite the fact that the marks which represent rational numbers on the rational number scale lie very dense on every part of the scale, they do not suffice for even very elementary computations. Thus, there is no rational number which measures the diagonal of a square of unit side. What do we mean when we say that the length of this diagonal is $\sqrt{2}=1.4141\ldots$? We mean that, although there is no mark on the rational number scale which represents the length of the diagonal of a square of unit side, yet if we laid this diagonal on the rational scale with one end at zero, the other end would lie in each interval of the following sequence of intervals (1,2), (1.4, 1.5), (1.41, 1.42), (1.414, 1.415) . . . , there being, conceptually, no end to this sequence despite the fact that each of the intervals is covered by, and is only one tenth the size of, the one that immediately precedes it. We regard this *nested* sequence as defining the *irrational* (= nonrational) number $\sqrt{2}$, and it is not difficult to define addition and multiplication of irrational numbers in terms of the corresponding operation on the rational end points of the various intervals of the nested sequences which define the irrational numbers. The addition and multiplication of irrational numbers arrived at in this way possess all the simple desirable features that characterize addition and multiplication of counting numbers (Stage 1) or of relative numbers (Stage 2) or of slope numbers (Stage 3); both addition and multiplication are commutative and associative, and multiplication is distributive with respect to addition.

I shall not enter into details, for there remain two stages in the evolution of the concept of number about which I want to say something. But I must add that these irrational numbers, defined by nested sequences of rational intervals, form, together with the rational numbers, the *real numbers*, which underly the subject known as calculus, and it is only the simple truth to say that no one can have any real understanding of calculus who does not know about them. Despite this fact, there seems to be a conspiracy of silence, motivated, no doubt, by the kindly but mischievous thought that the truth is too difficult or too dangerous for beginning students; of the tens of thousands of students who are today supposed to be learning the elements of calculus in our colleges less than one tenth of one percent ever hear of the nested intervals which define the numbers without which their subject would be impossible to develop. I here justify my rapid passage over this fourth stage of the evolution of the concept of number, the real number concept, by a plug. I have written an elementary calculus (published by the Remsen Press, 26 Court St., Brooklyn 2, N. Y.) in which you can find it all explained in terms suitable for a young boy or girl. In this book I have dared to tell the truth, but I have not dared to commit the crime of making the truth dull and uninteresting.

Stage 5

The complex number concept. In introducing the concept of a complex number, we follow exactly the same principle as when we introduced relative numbers. Just as a relative number was an ordered pair of counting numbers, so a complex number is an ordered pair of real numbers. Addition of complex numbers is defined by the same principle as in the case of relative numbers: *Respect the comma.* Thus, the sum of the two complex numbers (a,b) and (c,d) is the complex number $(a+c, b+d)$, and, just because we respect the comma, it is clear that this kind of addition possesses the desirable features of the addition of real numbers: it is com-

mutative and associative. We may mark our complex numbers on a scale, but, since we have to represent for each complex number *two* real numbers, our scale is no longer a line but a plane. Each complex number (a,b) is represented by a point in a plane. Actually we have two real-number scales, one horizontal and the other vertical, on the first of which we mark the real number a and on the second of which we mark the real number b. Thus we merely do *twice* for complex numbers what we have learned to do *once* for real numbers, and this is the only complexity involved. You will have understood from the previous discussion that we are not yet entitled to call our ordered pairs of real numbers complex *numbers,* for we have not yet defined the necessary rule of multiplication. They are, so far, only vectors, but now instead of being one-dimensional vectors, or vectors on a line, as were the relative numbers, they are two-dimensional vectors, or plane vectors. Thus the complex number (a,b) may be regarded as represented by the vector which carries us from the origin $(0,0)$ of our plane scale to the point (a,b) of this plane scale. But our vectors may start at any point, and so the complex number (a,b) may equally be regarded as represented by the vector which carries us from any point (c,d) of our plane scale to the point $(c+a, d+b)$ of this plane scale. The addition of our plane vectors follows the triangle law, in accordance with which we start the second vector where the first one ended, the sum of the two vectors being, then, the vector which carries us from the initial point of the first vector to the terminal point of the second vector. The zero vector $(0,0)$ is polite in addition.

When we try to make numbers out of these plane vectors we meet clearly a situation which was already present, although not so distinctly, in the first, or counting number, stage of the evolution of our concept of number. When you learned to multiply 3 by 5 you must have vaguely felt that there was some difference in the roles played by the two numbers 3 and 5. In forming 5 times 3, 5 was a kind of machine, or operator, the "multiplying-by-5 machine," into which we fed the number 3, the machine returning immediately the desired product. In forming 3 times 5, things are quite different; we have now a different machine, the "multiplying-by-3 machine," into which we feed a different number, 5 rather than 3, and this different machine immediately returns to us the desired product (which happens to be the same as the number returned to us by the other machine). In working with plane vectors, we have to devise a multiplying machine which feeds on vectors to produce vectors, and it turns out that the machines that do this most conveniently are *not* plane vectors. In order to keep in touch with the well-established notation, we write our plane vectors which represent our complex numbers in the form $\begin{pmatrix} a \\ b \end{pmatrix}$ rather than (a,b), and then the machines which feed on these plane vectors are blocks of four numbers like $\begin{pmatrix} p & r \\ q & s \end{pmatrix}$, which we may conveniently regard as built from two *column* vectors $\begin{pmatrix} p \\ q \end{pmatrix}$ and $\begin{pmatrix} r \\ s \end{pmatrix}$ or from two *row* vectors (p,r) and (q,s). If (p,r) is any row vector and $\begin{pmatrix} a \\ b \end{pmatrix}$ any column vector, we term the real number $pa+rb$ the product of the row vector (p,r) by the column vector $\begin{pmatrix} a \\ b \end{pmatrix}$. The result of feeding the column vector $\begin{pmatrix} a \\ b \end{pmatrix}$ into the multiplying machine $\begin{pmatrix} p & r \\ q & s \end{pmatrix}$ is, then, the column vector obtained by multiplying, one after the other, the rows of the machine by the column vector which is being fed into the machine. Thus:

$$\begin{pmatrix} p & r \\ q & s \end{pmatrix}\begin{pmatrix} a \\ b \end{pmatrix} = \begin{pmatrix} pa+rb \\ qa+sb \end{pmatrix}.$$

It is now easy to define the product of one machine by another; we merely feed, one after the other, the column vectors of the second machine into the first machine. Thus:

$$\begin{pmatrix} p & r \\ q & s \end{pmatrix}\begin{pmatrix} a & c \\ b & d \end{pmatrix} = \begin{pmatrix} pa+rb & pc+rd \\ qa+sb & qc+sd \end{pmatrix}.$$

This coupling of two multiplying machines has, as is easily seen, the disagreeable feature that it is noncommutative. It is sensitive to an interchange of the roles played by the two machines. If, however, we restrict our attention to those multiplying machines whose two column vectors are such that the second is obtained by rotating the first through a right angle in the positive sense, this disagreeable feature disappears. These special multiplying machines are of the form

$$\begin{pmatrix} p & -q \\ q & p \end{pmatrix},$$

and the product $\begin{pmatrix} p & -q \\ q & p \end{pmatrix}\begin{pmatrix} a & -b \\ b & a \end{pmatrix}$ of any two of them is of the same form, being

$$\begin{pmatrix} pa-qb & -(qa+pb) \\ qa+pb & pa-qb \end{pmatrix}.$$

It is these special multiplying machines, or two-dimensional square *matrices,* as they are called, that are to be our complex numbers. The plane

vectors $\begin{pmatrix} a \\ b \end{pmatrix}$ are not complex numbers; for, although these may be conveniently added, they may not be conveniently multiplied. A typical complex number is the two-dimensional square matrix $\begin{pmatrix} a & -b \\ b & a \end{pmatrix}$, and the laws of addition and of multiplication of complex numbers are expressed by the formulas:

$$\begin{pmatrix} a & -b \\ b & a \end{pmatrix} + \begin{pmatrix} c & -d \\ d & c \end{pmatrix} = \begin{pmatrix} a+c & -(b+d) \\ b+d & a+c \end{pmatrix};$$

$$\begin{pmatrix} a & -b \\ b & a \end{pmatrix}\begin{pmatrix} c & -d \\ d & c \end{pmatrix} = \begin{pmatrix} ac-bd & -(bc+ad) \\ bc+ad & ac-bd \end{pmatrix}.$$

It is easy to see that these laws possess all the desirable features of addition and multiplication that were so convenient in each of the four preceding stages of the evolution of the number concept; addition and multiplication are each commutative and associative, and multiplication is distributive with respect to addition. Furthermore, the complex number $\begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix}$ is polite in multiplication, and the complex number $\begin{pmatrix} 0 & 0 \\ 0 & 0 \end{pmatrix}$ is polite in addition. We now introduce a stenographic notation in accordance with which the special complex number $\begin{pmatrix} a & 0 \\ 0 & a \end{pmatrix}$ is denoted by the symbol a, and it is then clear that $b\begin{pmatrix} 0 & -1 \\ 1 & 0 \end{pmatrix} = \begin{pmatrix} 0 & -b \\ b & 0 \end{pmatrix}$. It follows that every complex number $\begin{pmatrix} a & -b \\ b & a \end{pmatrix}$ may be analyzed into the form $a + bi$ where i is a stenographic symbol for the complex number $\begin{pmatrix} 0 & -1 \\ 1 & 0 \end{pmatrix}$. This particular complex number i is such that its square is -1; in other words,

$$\begin{pmatrix} 0 & -1 \\ 1 & 0 \end{pmatrix}\begin{pmatrix} 0 & -1 \\ 1 & 0 \end{pmatrix} = \begin{pmatrix} -1 & 0 \\ 0 & -1 \end{pmatrix}.$$

This is all the mystery that lies in the imaginary unit whose square is -1. If any plane vector $\begin{pmatrix} a \\ b \end{pmatrix}$ is fed into the complex number (or multiplying machine) i, it is returned unchanged in length but rotated through a right angle in the positive sense. The machine, then, which is obtained by squaring the complex number i (i.e., by coupling i with itself) rotates every vector that is fed into it through two right angles. This is the geometrical interpretation of the statement that $i^2 = -1$. Before leaving this fifth stage of the evolution of the concept of number, I point out that associated with any complex number $\begin{pmatrix} a & -b \\ b & a \end{pmatrix} = a + bi$ is another complex number $\begin{pmatrix} a & b \\ -b & a \end{pmatrix} = a - bi$, which we term the *conjugate* of the original complex number; the product of the two conjugate complex numbers $a + bi$ and $a - bi$ is the complex number $\begin{pmatrix} a^2+b^2 & 0 \\ 0 & a^2+b^2 \end{pmatrix} = a^2 + b^2$. If we use the single symbol β to denote the complex number $a + bi$ then we denote by $\overline{\beta}$ the conjugate number $a - bi$ to $\beta = a + bi$.

Stage 6

The quaternion number concept. The concept of quaternions is developed from the concept of complex numbers in exactly the same way as the concept of complex numbers was developed from the concept of real numbers. Our new numbers are still two-dimensional square matrices, but now the coordinates of the two column vectors are complex numbers. The second column vector is determined, once the first column vector is given, by the following rule: If the first column vector is $\begin{pmatrix} \beta \\ \delta \end{pmatrix}$, then the second column vector is $\begin{pmatrix} -\overline{\delta} \\ \overline{\beta} \end{pmatrix}$. Thus a typical quaternion is of the form $\begin{pmatrix} \beta & -\overline{\delta} \\ \delta & \overline{\beta} \end{pmatrix}$, where β and δ are any two complex numbers, just as a typical complex number was of the form $\begin{pmatrix} a & -b \\ b & a \end{pmatrix}$ where a and b are any two real numbers. We term, after Hamilton, these new numbers *quaternions*, because four real numbers are necessary to specify any one of them; namely, the two real numbers a and b which serve to define $\beta = a + bi$, and the two real numbers c and d which serve to define $\delta = c + di$. If we define the squared magnitude of any complex two-dimensional vector $\begin{pmatrix} \beta \\ \delta \end{pmatrix}$ to be $\overline{\beta}\beta + \overline{\delta}\delta$, we may say that the two complex column vectors of the typical quaternion $\begin{pmatrix} \beta & -\overline{\delta} \\ \delta & \overline{\beta} \end{pmatrix}$ are equally long and mutually perpendicular, just as the two real column vectors of the typical complex number $\begin{pmatrix} a & -b \\ b & a \end{pmatrix}$ are equally long and mutually perpendicular. The rules of addition and of multiplication of quaternions are given by the formulas:

$$\begin{pmatrix} \beta & -\overline{\delta} \\ \delta & \overline{\beta} \end{pmatrix} + \begin{pmatrix} \lambda & -\overline{\mu} \\ \mu & \overline{\lambda} \end{pmatrix} = \begin{pmatrix} \beta+\lambda & -(\overline{\delta+\mu}) \\ \delta+\mu & (\overline{\beta+\lambda}) \end{pmatrix};$$

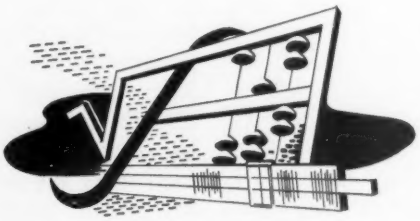
$$\begin{pmatrix} \beta & -\overline{\delta} \\ \delta & \overline{\beta} \end{pmatrix}\begin{pmatrix} \lambda & -\overline{\mu} \\ \mu & \overline{\lambda} \end{pmatrix} = \begin{pmatrix} \beta\lambda-\overline{\delta}\mu & -\beta\overline{\mu}-\overline{\delta\lambda} \\ \delta\lambda+\overline{\beta}\mu & \overline{\beta\lambda}-\delta\overline{\mu} \end{pmatrix}.$$

and it follows that addition is commutative and associative and that multiplication is associative and distributive with respect to addition. We have had, however, to sacrifice in this final stage of the evolution of the concept of number the commutative property of multiplication; multiplication of quaternions is not in general commutative. It is easy to see that if we use the stenographic symbols 1, i, j, k, for the quaternions $\begin{pmatrix}1&0\\0&1\end{pmatrix}$, $\begin{pmatrix}0&-1\\1&0\end{pmatrix}$, $\begin{pmatrix}i&0\\0&-i\end{pmatrix}$, $\begin{pmatrix}0&i\\i&0\end{pmatrix}$, the general quaternion $\begin{pmatrix}\beta&-\bar{\delta}\\\delta&\bar{\beta}\end{pmatrix}$, where $\beta = a + ib$, $\delta = c + id$ may be analyzed into the form $a + ci + bj + dk$. The quaternion units i, j, k are easily seen to satisfy the relations

$$i^2 = j^2 = k^2 = -1\,;\ jk = -kj = i\,;$$
$$ki = -ik = j\,;\ ij = -ji = k.$$

The four matrices $\begin{pmatrix}1&0\\0&1\end{pmatrix}$, $\begin{pmatrix}0&-1\\1&0\end{pmatrix}$, $\begin{pmatrix}i&0\\0&-i\end{pmatrix}$, $\begin{pmatrix}0&i\\i&0\end{pmatrix}$ were used to great effect by Pauli, some twenty-five years ago, in connection with the quantum theory of the spinning electron and are frequently referred to as the Pauli matrices.

This ends, then, my survey of the six stages in the evolution of the concept of number, and I can see the obvious query framing itself. Why, other than for considerations of time and mercy, stop there? What about the seventh, eighth, and so on stages? Well, there is a remarkable theorem, proved some sixty years ago, that this is all the stages there are if you refuse to sacrifice the associativity and commutativity properties of addition, the associativity and distributive property with respect to addition of multiplication, and also demand that there are no divisors of zero; i.e., that if the product of two numbers is zero, one or the other of them must be zero. The only number systems that possess these properties are (1) the counting numbers, (2) the integers, (3) the rational numbers, (4) the real numbers, (5) the complex numbers, and (6) the quaternions. In my discussion I have made it clear how important for the basic fundamental concepts of mathematics are, in my opinion, the concepts of vectors and matrices. If any of you happen to teach mathematics, please break your conspiracy of silence and tell your beginning students about these simple, interesting things. You do not have to go deeper into the subject than two-dimensional, or at most three-dimensional, matrices. After all, the application by Pauli of his two-dimensional matrices to the theory of electron spin was a valuable scientific contribution which gained him a lot of fame. The fact that these Pauli matrices are merely a representation (in the field of complex numbers) of the quaternions discovered more than a century ago by the great Irishman Hamilton is for me a matter of national pride.



CRYSTAL RESEARCH

PAUL H. EGLI

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CRYSTAL research has become fashionable along with the development of the "solid state" as an important branch of science, and in many instances the two fields are synonymous. Early crystal work was necessarily confined to the external features and was conducted largely by mineralogists and a small school of theoretical scientists in the days when the gap between chemistry and physics was first being bridged. With the exciting discovery of X-ray diffraction, real progress on exploring the interior of solids became possible, and an increasing number of the most able physicists became interested in atomic and classical problems in crystal physics. The question of how crystals were formed, however, continued to receive little attention.

Within recent years a widespread recognition of the importance of crystal formation has developed in many fields of science. In metallurgy, for example, it is recognized that many of the problems are concerned with the crystalline texture of the material, and crystal formation is receiving the attention of outstanding physical metallurgists. Similarly, contributions are being made from the viewpoint of problems in ceramics, explosives, luminescent materials, paints, and in many seemingly unrelated fields.

The most active interest has arisen in connection with the development of a variety of applications for single crystals as such, and it is this work with which this discussion is primarily concerned. Most of the applications are connected in a broad sense with optics and communications. The general principles of the use of crystals as windows, lenses, prisms, and filters in optical instruments are well known, but some of the electronic possibilities have been less widely described. Telephone and telegraph circuits use crystals in their transmission networks to separate the various messages carried simultaneously on the same cable. Radio and radar use crystals in microphones, in earphones, to control the wave length of the transmission, and for circuit elements to replace vacuum tubes in various ways. Sonar gear uses crystals as both the generator and detector of sound in underwater echo-ranging. Crystals are being used as the source of ultrasonic energy for effecting chemical reactions and physical changes in materials. Several methods of detecting and measuring nuclear radiation are based on various properties of crystals.

The growth of single crystals is achieved by a variety of techniques, but often a particular growth method goes hand in hand with a particular application. For example, crystals for high-frequency oscillator control must have chemical stability, mechanical rigidity, and sufficient asymmetry in structure to permit a moderately strong piezoelectric effect. These properties are associated with materials which have high Debye temperatures and which are generally too insoluble for normal growth from solution. The complex structures lead to instability at the melting temperature or to symmetry transitions during cooling, so that melt growth techniques are eliminated. Thus, crystals of possible use as high-frequency oscillators must almost invariably be grown by hydrothermal (high temperature-pressure solution) techniques. Optical applications normally require physical properties such that the crystals can only be grown by a melt process; and other applications are similarly linked with crystals grown in a particular way.

The familiar type of crystal growth from solution is useful in industry only for the materials used in airborne and underwater sound devices, but the widespread use of phonograph pickups, and the large number of crystals used by the Navy in antisubmarine warfare, have been sufficient to support a sizable industry. Moreover, crystal growth from solution lends itself readily to changing the process variables, so that it is a convenient method by which to study the factors that control the growth mechanism and has accordingly received the most attention from crystal chemists.

Certain general principles, helpful in attacking the synthesis of crystals of a new material, have been established for crystal growth. For the most part, these growth principles have been established by observation, and the theoretical explanations are only partially satisfactory. The thermodynamic conditons necessary for growth were stated in an excellent manner by Gibbs in 1865, but progress

since then toward a usable kinetics for the nucleation processes has been trivial. Crystallization is usually considered in terms of two factors: the diffusion of material from the surrounding supercooled medium to the crystal surface, and the chemical reaction of addition of new material to the surface. This is expressed most simply as a typical rate equation

$$N = C\ e^{\frac{-Q}{KT}} \cdot e^{\frac{-W}{KT}} \qquad \text{(Equation 1)}$$

where N = number of units added per unit time. The first factor, following the constant C, governs the transport of material to the crystal (Q = the activation energy of the diffusion process), and the second factor governs the reaction at the crystal surface (W = the activation energy required to add a unit to the crystal). In aqueous solution, Q is relatively small and remarkably constant regardless of the salt. Moreover, the role of diffusion in the process can be minimized by proper agitation, so that this step is seldom the controlling factor in solution growth.

The surface reaction, which is thus normally the controlling factor, remains too complex to calculate. A qualitative conception of the process can be visualized by use of a diagram first used by Kossel (Fig. 1). Local energy fluctuations constantly deposit and dissolve material at the surface. New units are more likely to become attached at those places on the surface where they will be most tightly bound to existing crystal surface. The highest activation energy is required to add a new unit at a corner to form a new layer, whereas an appreciably small fluctuation can add new material to a partially completed row. Growth is thus pictured as proceeding in a rhythmic fashion, pausing for a large fluctuation to add material at a corner to start a new layer, proceeding more readily along the edges, and quickly filling in row after row to finish the layer.

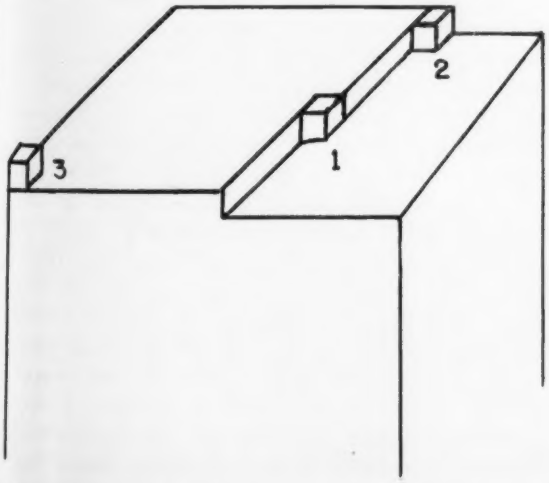


FIG. 1. Diagram illustrating sequence in which new material adds to a crystal surface in an ideal process.

Numerous elaborate relations have been developed to describe this process, but the necessary physical constants are not available to make them generally useful. A simple statement of a widely accepted viewpoint was presented by Landau as:

$$\Delta F = 2\beta\sqrt{\eta} + (\mu' - \mu)\,\eta \qquad \text{(Equation 2)}$$

ΔF is the free energy change for adding η ions to a surface

β is a constant for the "edge" energy per particle

η is the number of ions

μ' is the chemical potential per particle in a crystal

μ is the chemical potential per particle in a solution

This relation refers to the process of adding a two-dimensional group to the crystal surface.

An expression can be derived from this equation which states that a certain critical number of ions must be collected before a group on the surface is thermodynamically stable. Thus by differentiating and equating to zero,

$$\eta_0 = \frac{\beta^2}{(\mu - \mu')^2}. \qquad \text{(Equation 3)}$$

where η_0 = the critical size of a stable two-dimensional group. The activation energy W in equation (1) is then synonymous with the free-energy change necessary to form a group larger than the critical size η_0 in equation (3). In terms of the Kossel diagram, the critical size necessary for stability would be smaller for a group added at point (1) than at point (3).

The same arguments used for the growth process can be applied to the problem of nucleation, where similarly energy fluctuations must form an aggregate greater than the critical size of a stable nucleus. Recently considerable publicity has been given to the concept of an intermediate size aggregate (called an "embryo" by Frenkel) which by statistical theory has a finite existence even though it is too small to be thermodynamically stable. A bucket of water, for example, no matter how hot, is conceived as containing several hundred particles of ice. This concept makes it easier to explain how the larger-sized groups necessary for a stable nucleus can be formed. Otherwise, to form a nucleus would require large fluctuations which bring together the whole group more or less simultaneously; this is implausible from the viewpoint of statistics. The question is far from settled, however, as witness the fact that at a recent symposium on crystallization, the best-qualified guesses as to the number of ions or atoms in a nucleus at its critical size varied from 1 to 23,000.

FIG. 2. *Right*: Typical result of an attempt to grow NaCl from pure solution; *left*: result obtained by addition of small amount of lead ion to the solution.

Despite the lack of rigor of the theories of crystallization, the qualitative concepts they imply are helpful in guiding experiment. For example, one of the critical features in growth of large single crystals from solution is preparation of the solution so as to inhibit the formation of unwanted spontaneous nuclei. This involves certain obvious things such as very careful filtering to remove dust and similar small foreign particles, because the high surface energy of such material furnishes preferred spots for nuclei to develop. Less widely recognized is the necessity for vigorously heating the solution for an appreciable period beyond the time when the solute is apparently well dissolved. The long time required to dissolve the last traces of submicroscopic particles that could serve as nuclei is somewhat surprising in view of the well-known fact that small particles become increasingly soluble as size diminishes. This supersolubility effect is explained by the same considerations used to show that nuclei are not stable below a certain critical size, but the rate of the solution process is a more complicated matter. A plausible explanation of the persistence of nuclei in a superheated solution depends on the fact that solution takes place more readily at certain spots on a crystal surface—usually in the reverse order of the ease of growth—and the process becomes slower as the shape of the crystal changes with the loss of the more easily dissolved portions.

As implied from the theory, the two controllable factors which govern the rate of the growth process are the degree of supersaturation and the agitation. Supersaturation, which forces material to precipitate out of solution onto the seed, can be achieved in a variety of ways. On a laboratory scale, evaporation is generally the easiest method to control. On a larger scale, gradual temperature change—lowering for normal salts—is more convenient. In some cases there are advantages to using a system in which the solution is kept in equilibrium with the solute in a separate container, at a temperature slightly supersaturated with respect to the temperature of the growing chamber. By whatever means supersaturation is obtained, the success of the growth process depends on precise control of this factor. The problem is to maintain sufficient supersaturation to force a rapid growth rate without inducing spontaneous nuclei and without depositing material so rapidly that it is misorientated, thus causing flaws. Growth is slow at best; two inches a month is considered good even for crystals that grow with relative ease. The only way to make the process sound fast is to translate this to atomic terms, in which case it is 5,000 atomic planes per minute.

The permissible growth rate depends partly on the composition of the solution, and this can be varied to some extent. The optimum purity of the solution is an important factor in all growth processes, and nothing in the existing theories is very helpful. It is not true—as generally stated—that crystals grow better from very pure solutions. On the contrary, it is virtually impossible to grow large crystals of such a common thing as table salt from solution without the intentional addition of impurities. Figure 2 shows a typical result of an attempt to grow NaCl from pure solution and the result obtained by the addition of a small amount of lead ion to the solution. Of the several hundred different crystals investigated at the Naval Research Laboratory, growth of nearly all was improved by the addition of selected impurities. The type and amount of ion that was most effective proved different in nearly every case, and only the roughest sort of generalizations have been developed to aid in the selection of the proper composition for a new growth problem. Heavy multivalent cations are frequently the most useful additions, generally in concentrations below one part per hundred by weight in the solution. Larger concentrations result in growth that is worse than

from pure solution and frequently modify the habit of the number and relative size of external faces.

Habit modification has been the subject of intensive investigation from the time of Robert Boyle in 1690, but it remains about as mysterious as it was then. Much of this work was concerned with the action of dyestuffs, and many colorful effects have been achieved by virtue of the fact that the dyes were absorbed on certain faces and not on others in the same crystal. The information thus acquired has been helpful in interpreting growth rate and face development in some types of compounds, but the general pattern remains vague.

Absorption of the foreign materials into the crystal is not a necessary part of the habit-modifying process, and in the case of the ions used to improve growth, as described above, the amount retained in the finished crystal is often undetectable by common analytical techniques. Virtually

FIG. 3. Completed NaCl crystals, showing manner in which they are mounted for providing agitation.

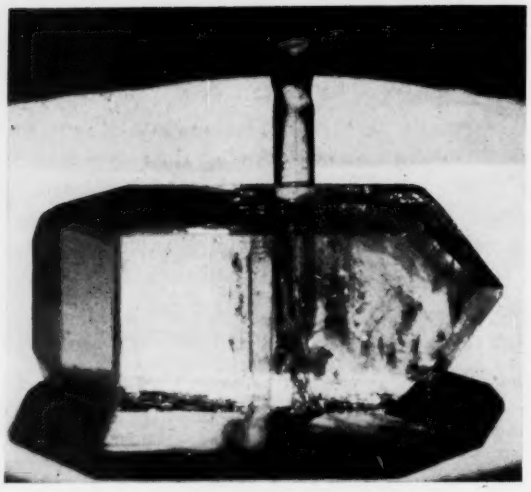


FIG. 4. HIO_3 crystal. Showing flaws induced by growth enclosing the supporting rod.

undetectable amounts of impurities in the crystal may, however, alter the physical properties appreciably. As little as six parts per million of certain contaminants increases the conductivity of ammonium phosphate by a factor of ten. For this reason, it is generally desirable to do the best possible job of removing all impurities from a solution intended for crystal growth and, subsequently, to add the desirable foreign ions.

The other major factor in solution crystal growth is the agitation which removes depleted solution from contact with the crystal surface—decreasing the path of diffusion—and prevents convection currents induced by the heat of crystallization from causing misoriented growth. Slight differences in the amount of agitation often change the growth rate by a factor of two or three, so that the efficiency of the whole process may depend on this variable. In many solutions, apparently depending on the viscosity, a point is reached beyond which additional agitation is of little value, but no ill effects have been observed from increasing agitation up to the point of visible turbulence, which may induce spontaneous nuclei.

A variety of ingenious schemes, many of them patented, have been described for achieving the necessary agitation, but none is a cure-all. The most effective technique in many cases is to mount the growing crystals on a rack, which is rotated in the solution (Fig. 3). In this way the rate is easily controlled and seeds can be mounted so that the rapidly growing faces receive the maximum benefit. An advantage is obtained in some instances by reversing the direction of rotation periodically. The scheme is not universally useful, however, because many crystals crack as growth encloses the supporting rod, regardless of the diameter or material of construction (Fig. 4). In other cases the crystals are sensitive to the tiny vibrations of the stirring motor, or the shape of the product desired may not be convenient for this system. In these instances schemes can usually be employed which involve variations of stirring the solution or rocking the container so that the solution swirls past rigidly mounted seeds.

Another important consideration in growth from solution is selection of the seed on which new growth can deposit. In general, any fragment of previously grown or natural crystal of the desired material can be used, or if none is available, small crystals can be obtained by very slow evaporation of solution in a beaker completely free of agitation. For high efficiency, however, it is necessary to use sections cut in certain crystallographic directions. Normally, the best seed is a section parallel to one of the smaller faces of a completely formed crystal. Crystals grow at different rates in different directions because new material is more readily attached to certain atomic planes; Figure 5 shows how this results in small faces normal to the rapidly growing directions. A seed plate cut in one of the slower growing directions eventually develops the normal faces, but the process is time-consuming. Growth along the smaller faces frequently has sufficient advantage over other directions that those faces project ahead of the main body of a seed until the new faces are completely formed, enclosing a hollow section. This is strikingly demonstrated on ammonium phosphate seeds cut normal to the long direction in the crystal (Fig. 6).

From an engineering viewpoint, the exploitation of crystals grown from solution has been highly successful. Much of the credit belongs to The Brush Development Company, which pioneered in

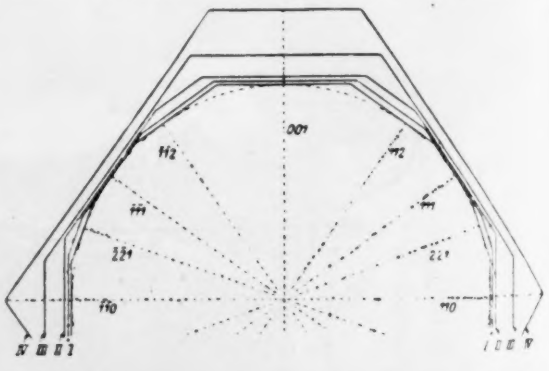


FIG. 5. Diagram illustrating how faces normal to rapidly growing directions diminish in successive stages of growth on a sphere.

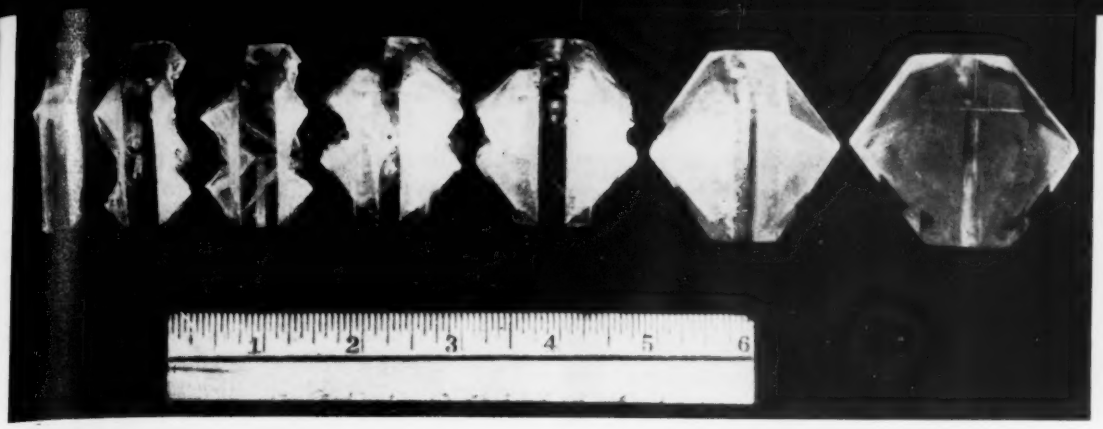


FIG. 6. Successive stages in capping process in the growth of ammonium dihydrogen phosphate. The seed is a plate normal to the long direction. Growth occurs only at the perimeter (center of plate can be cut out without effect), and the enclosed pyramids are hollow.

the production of Rochelle salt for use in both audio devices and underwater sound gear. Rochelle salt units still have no serious competition for high-fidelity reproduction equipment, and high-quality units have long been available at a reasonable price for use in home phonograph pickups. Rochelle salt also made possible the first major improvements in underwater sound gear after the original development of quartz transducers by Langevin in France during the first world war.

More recently, the piezoelectric properties of literally hundreds of crystals have been investigated and several new materials developed for special applications. The value of a crystal as an electroacoustic transducer depends on the amount of piezoelectric response for a particular mode of vibration. Of the thirty-two classes of symmetry, twenty exhibit a piezoelectric effect, and each of these classes is limited by symmetry to electrical response from elastic deformations in certain definite directions. For underwater sound gear a longitudinal response is most convenient, and Rochelle salt remains the most sensitive for this purpose. Early in World War II, a new crystal, ammonium dihydrogen phosphate, was developed —again largely by the Brush Company—which is considerably more rugged, both chemically and electrically, and has sufficient piezoelectric response to be usable. Within eighteen months after the first measurements on tiny crystals, large-scale production of beautiful material was in progress (Fig. 7), and all sound gear constructed during the last part of the war employed the new crystals.

More recently, a new crystal, lithium sulfate monohydrate, has been developed—independently by NRL and the Brush Company—for its strong response to hydrostatic pressure. Its piezoelectric sensitivity is about seven times that of tourmaline, which had previously been employed for absolute sound-intensity measurements and similar applications for which a hydrostatic response is necessary.

For oscillator control, the essential requirement is a combination of piezoelectric and elastic properties which result in a constant resonant frequency over a wide range of temperature. Several new materials, potassium pentaborate, dipotassium tartrate (similar to Rochelle salt), and ethylene diamine tartrate, have been developed which are valuable for low-frequency applications such as telephone circuits. For Swiss radio networks, which operate at lower frequencies than those in America, the Federal Technical School at Zurich has developed potassium dihydrogen phosphate.

Quartz remains the only crystal with a high frequency, shear piezoelectric response, and a small frequency change with temperature suitable for oscillator control of American radio and television frequencies. Intensive efforts are in progress

FIG. 7. Completed tray of ammonium dihydrogen phosphate crystals. Used principally in underwater devices.

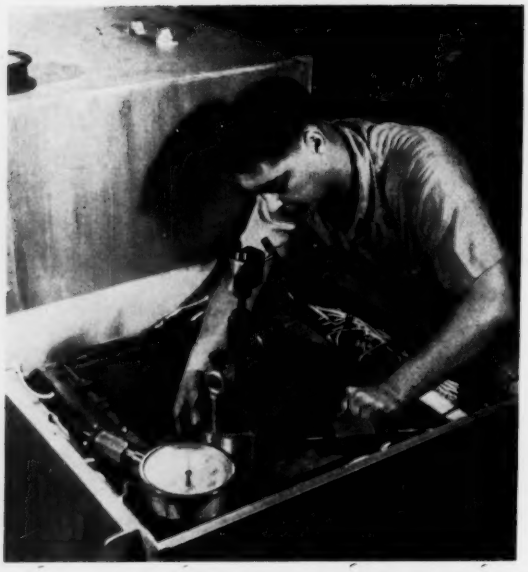


FIG. 8. Furnace and high-pressure vessel used for hydrothermal synthesis of quartz.

to synthesize quartz or a suitable replacement, but in every case the materials require hydrothermal synthesis. The growth problems are quite similar to normal crystal growth from solution except that high temperatures and pressures are required to dissolve the material. Most of the work in this field has been concerned with synthetic quartz, and growth on a small scale is already highly successful. An efficient large-scale process awaits the solving of some engineering problems, none of which appear to be major obstacles.

None of the possible substitute materials is likely to be developed very quickly because the scarcity of data on high temperature-pressure systems necessitates an elaborate phase-equilibrium study for each crystal before growth experiments can be efficiently conducted. Moreover, the difficulties of hydrothermal techniques make for slow progress because of the heavy equipment (Fig. 8) necessary for the high temperatures and pressures; so that even the synthesis of small particles of the correct composition is far removed from successful crystal growth.

Natural quartz and calcite have been important optical materials, but they can now be replaced to advantage by a number of synthetic crystals. Sodium chloride was the first widely used synthetic and is typical in that it is a simple-cubic halide, stable at high temperatures, and easily grown from the melt. The common process—developed on an industrial scale at the Harshaw Chemical Company—involves a crucible with a conical bottom lowered slowly through a furnace with a sharp temperature gradient at the melting point of the crystal. A single crystal forms in the bottom of the cone as the melted material reaches the gradient section of the furnace, and the remainder of the material deposits on that seed as it in turn solidifies. Figure 9 shows an elevator mechanism and a complete boule being removed from the furnace. An alternate method involves getting a nucleus of material solidified on the tip of a cool rod and slowly withdrawing it from a crucible of melted material.

A considerable variety of optical crystals is now available, each useful for a particular spectral range. Recent work has been concerned with thallium halides, particularly a solid solution of thallium bromide-iodide, which was developed by the Germans during the recent war for transmission in the far infrared (5–40 μ). Silver chloride remains a valuable material for infrared optics because of the great ease with which it is grown, and the fact that it can be easily rolled into thin sheets or pressed to desired shapes without losing its crystalline form.

Crystals grown from the melt are also in considerable demand by solid-state physicists since the simple-cubic structures readily grown by this method are amenable to investigation. A wide

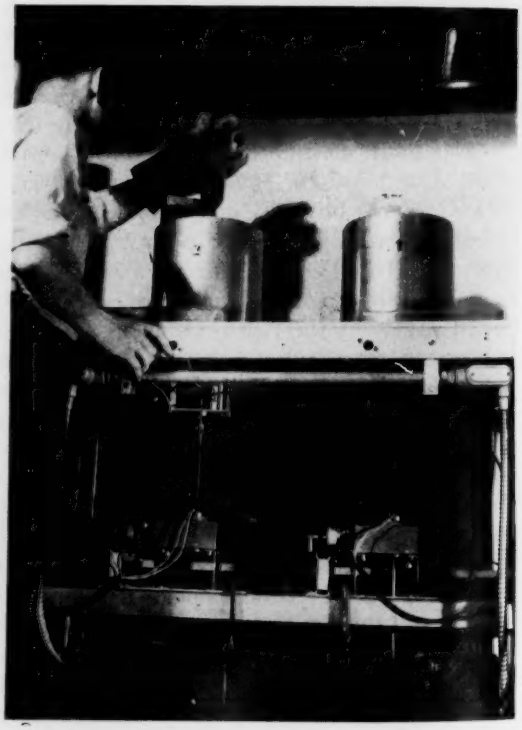


FIG. 9. Electric furnace and elevator mechanism for the crucible-melt process. The completed crystal is KRS-5 (thallium bromide-iodide) in a glass crucible.

variety of pure compounds, solid solutions, and crystals with controlled lattice defects and impurities are all being investgated with respect to fundamental optical, electrical, mechanical, atomic, and nuclear phenomena.

The melt technique has also been used for certain types of semiconductor materials, including silicon and germanium, which are widely used as high-frequency rectifiers. The very recent development of crystal amplifiers by the Bell Laboratories has created new interest in this type of material. In a demonstration test, all the tubes in a house-

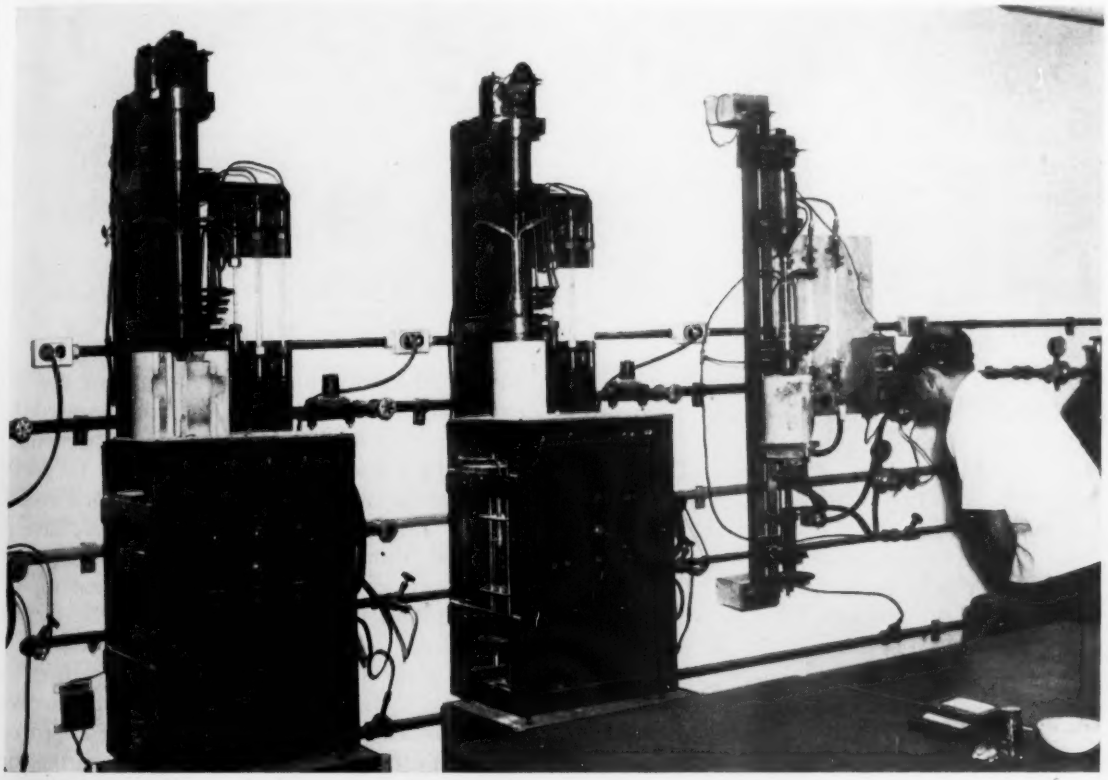


FIG. 10. Equipment for growing crystals by the flame fusion method. (Photo by courtesy of the Titanium Division, National Lead Co.)

hold radio were successfully replaced by tiny crystals.

By extending the temperature range of electric furnaces, several minerals that are not available as pure crystals from nature have been grown. Of particular interest are scheelite and a series of similar tungstate compounds which emit luminescent scintillations in a manner that provides a sensitive measurement of nuclear radiations.

The tungstates have also been grown by an alternate technique for high-temperature materials, the flame fusion process. This technique was developed by Verneuil and improved to an efficient industrial process by the Linde Air Products Company. A finely powdered reagent is fed evenly into the oxygen stream of an oxyhydrogen burner of special design. The material is fused in the flame and crystallizes on a ceramic support surrounded by an insulating jacket (Fig. 10). The ceramic rod is lowered as the material deposits to form a boule. Considerable witchery is involved in this technique, and for a new material the success is likely to depend on the skill of the operator. Production has been limited to corundum (Al_2O_3) and spinel ($MgO \cdot Al_2O_3$), with small concentrations of additional metal ions to produce a variety of colors, e.g., for synthetic rubies. Important applications have been developed for these crystals as instrument and watch bearings and for certain other applications where hardness is important, such as thread guides, but the largest market has been as synthetic gems. The reluctance of the jewelry trade to accept synthetic stones as high-grade gems has received two serious setbacks recently. One was the development of star sapphires by the Linde Company. These gems are high-quality sapphire with unusually well-defined stars, and are being well received as expensive stones. The other de-

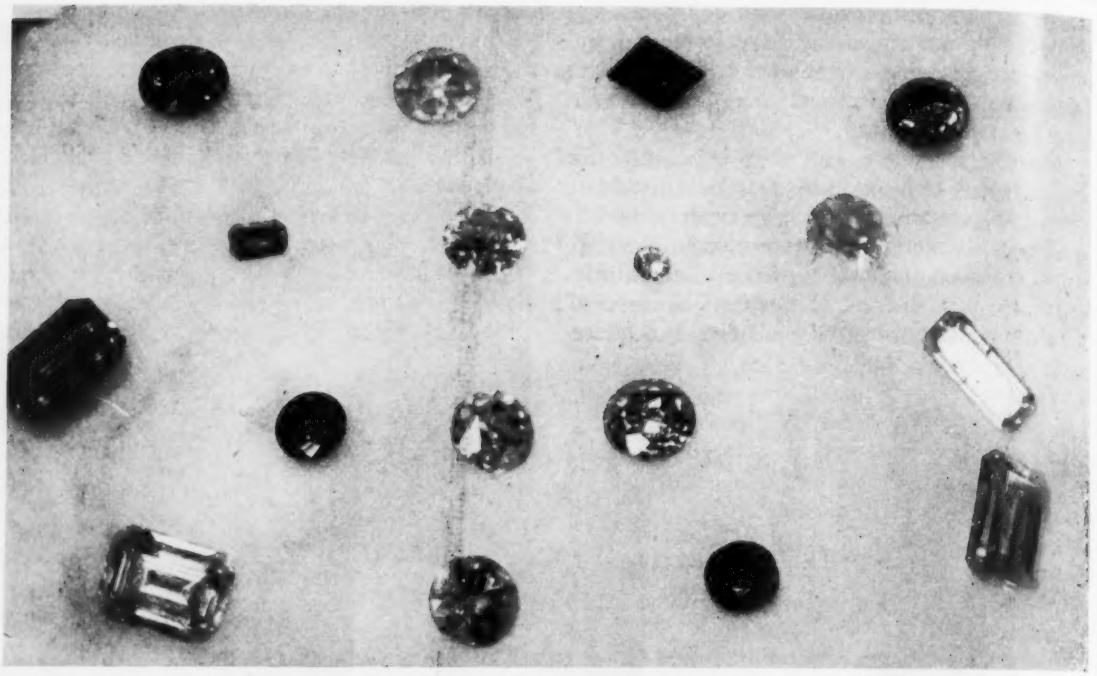


FIG. 11. Display of cut rutile gem stones. (Photo by courtesy of the Titanium Division, National Lead Co.)

velopment, even more recent, was the flame fusion synthesis of rutile (TiO_2) by Dr. Charles H. Moore, Jr., of the Titanium Division of the National Lead Company. This material, which at present is produced only as a faint yellow stone, has an appreciably higher dispersion than diamond, and when faceted in the same manner is an exceptionally brilliant gem (Fig. 11).

Rutile is also interesting for its unique electrical properties. By slight variations in the oxygen content, the material can be changed from a superdielectric to almost a metallic conductor, so that it promises to be a profitable material on which to investigate basic electrical phenomena.

A great many compounds remain for which no suitable method of crystal growth has been devised. This is particularly true for a large body of compounds that are unstable at their melting points and highly insoluble even at high temperatures and pressures. Among such compounds are many oxides, sulfides, and other typically semiconductor materials which are needed for investigation of photoconductivity, luminescence, and similar electronic processes. Improved crystals are needed in vital applications that depend on these phenomena. Some slight success has been achieved by growth from the vapor phase—such as the work on CdS by Frerichs; all such attempts, however, have resulted in thin plates or needles, and the vapor phase appears to be inherently unsuited for efficient growth of large crystals regardless of the technique.

One growth possibility that has not been exploited is a melt process under high-pressure controlled atmospheres, and plans are now in progress for such attempts. Another possibility is the combustion of a neutral gas to avoid the problem of chemical reduction in the oxyhydrogen flame fusion process. Whatever the techniques developed, future crystal research would appear to require considerable ingenuity, but the incentive is sufficiently great to insure that the necessary methods will be developed. Progress in many fields of science depends on obtaining single crystals on which to base future research.

SCIENCE ON THE MARCH

CANCER CHEMOTHERAPY

UNTIL recently the only effective measures for treating cancer involved the use of radium or X-rays or surgery. Sometimes surgery and irradiation were combined. Other therapeutic efforts consisted essentially of supportive treatment such as analgesics for the relief of pain, vitamins and proteins to counteract the loss of appetite and weight, and the treatment of anemia. When cancer is diagnosed and the patient treated early the majority of sufferers can be saved from dying of the effects of a malignant growth. For example, 75 percent of early cases of cancer of the breast are curable; over 90 percent of early cases of cancer of the skin can be saved; and over 80 percent of early cases of cancer of the uterus are curable. Cancer of the lung and of the stomach, intestine, and elsewhere are also responsive.

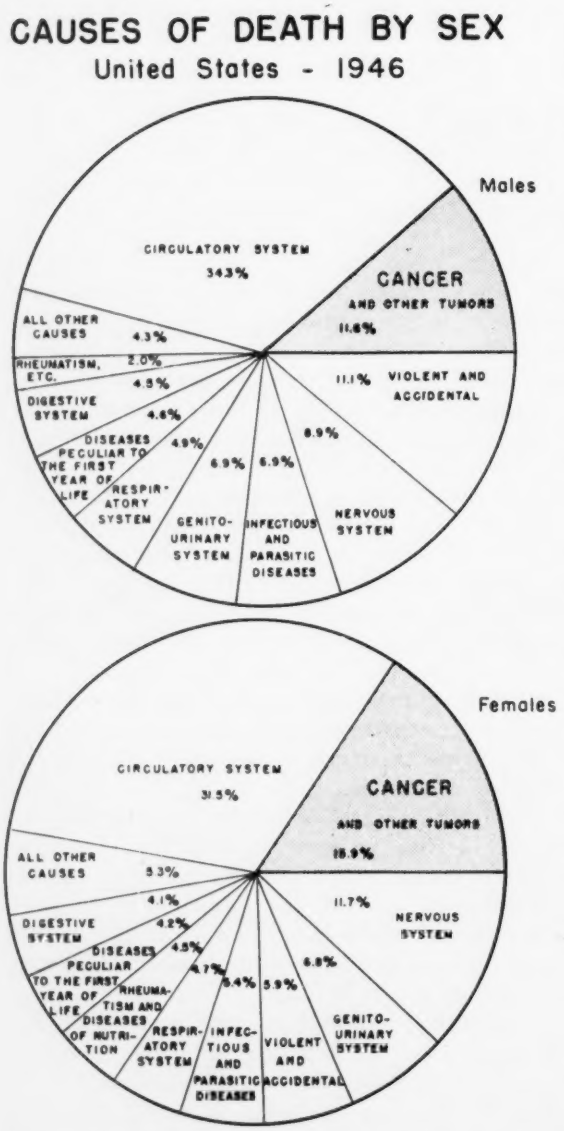
Although such encouraging facts have changed completely the outlook for the patient with a malignant growth, often he does not seek treatment when he can be cured of his disease. Sometimes surgery may prove fatal. And, occasionally, the tumor is not accessible to surgery or irradiation. In these cases other treatments would be of inestimable value.

In a promising vein, discoveries have been made within the past few years that offer hope of obtaining further control over cancer. Several avenues have been followed, but the most interesting approach at the moment involves chemical investigations. In fact, so much of value has been studied that it has become almost impossible to correlate all the data and to explore all the divergent hypotheses. Certainly they cannot be set forth in one brief article. One aspect of the newer research is related to the use of endocrine and endocrinelike preparations, and some details concerning this phase of investigation may be interesting, since good therapeutic effects have been obtained in the endocrine therapy of cancer. There are some researchers who have advanced so far in their studies that their work is said to form the basis of a specific phase of investigation, cancer chemotherapy.

Less than a decade ago, there appeared a report indicating that the synthetically prepared chemical diethylstilbestrol, which is capable of eliciting responses in the body similar to those obtained by the administration of estrogens, can influence the course of prostatic carcinoma. Surgical castration was known to achieve similar results, and some individuals began to speak loosely of "hormonal castration." The fallacy of such a term in our present state of knowledge is obvious, but its suggestiveness did provoke, nevertheless, some interesting contemplation. In spite of conflicting reports, it was evident that the use of estrogens with or without castration increased the survival rate of those suffering with prostatic carcinoma, relieved pain, and permitted increase in weight, appetite, and vigor. It was equally apparent that such treatment was palliative and not curative.

Following these earlier observations, research workers demonstrated that endocrines might have value for the treatment of cancer elsewhere in the body—for example, in the breast. This probably seemed surprising to some individuals, because researchers have known for years that excessive doses of certain endocrines can cause, at least in experimental animals, the formation of tumors; but it merely reflects once again the variations that occur in body responses as the intensity of potent influencing factors is varied.

As might be expected, cancer chemotherapy became such a lively topic that research spread in all directions. Many investigators studied the effects of hormones on tumor processes and published their results, often without being aware of what was under investigation in other laboratories. Time sometimes is lost because of lack of knowledge of data held by the various researchers and by repetition of work already completed but not reported. Because of the importance of the cancer problem and the need for advancing research in this field as quickly as possible, there was formed by the Therapeutic Trials Committee, a standing committee of the Council on Pharmacy and Chemistry of the American Medical Association, a subcommittee to encourage the coordination of effort of clinical researcher and drug manufacturer. Already certain conclusions can be drawn. Early in its organization this subcommittee warned that steroid hormone therapy does not provide a cure for carcinoma of the breast, the malignancy origin-



ally studied by this group. Since then other malignancies have been under consideration, but there still is no indication that this form of therapy is more than palliative; in certain carefully selected cases symptomatic relief is definitely provided, and the life expectancy in some individuals may be prolonged. On the other hand, there is urgent necessity for proper selection of cases for steroid hormone therapy, and the possible dangers of careless choice and mismanagement of cases cannot be emphasized too strongly. Furthermore, as the research progresses new protective findings arise; for example, estrogen administration may cause water retention, which may influence a weakened heart unfavorably.

Radical surgery with or without roentgen radiation is the only procedure recommended for curable malignant lesions, but careful selection of patients whose disease has progressed too far for operation may permit hormone treatment. Androgen therapy sometimes is of help to patients with metastatic lesions in bone, there following within two or three weeks relief from pain, increased appetite, gain in weight, less need for narcotics, and renewed interest in life. The relief is comparable to that seen in cases of prostatic carcinoma after castration. Beneficial results are seldom observed on the primary disease or soft-tissue metastases, although intensive testosterone therapy in premenopausal women may lead to a so-called chemical or medical castration which will result in changes in soft tissue. At the same time the bone undergoes some repair and regeneration, as observed by roentgenologic studies and changes in the chemical findings in the blood. The duration of relief is variable, as recurrences ensue, but further treatment may be given.

The criteria for the selection of patients for estrogen therapy differ from those for androgen therapy. Favorable effects appear in older women who have soft-tissue lesions, definite regressions often occurring in the primary tumor and the metastases. There is considerable variation in the responses among individual patients, and relief usually persists for comparatively short periods only.

The scope of the project undertaken by the Subcommittee of the Therapeutic Trials Committee can be estimated by the number of current collaborators: fourteen manufacturers of the androgens and/or estrogens and fifty clinical centers are pooling their efforts and knowledge. Furthermore, the Cancer Grants Division of the National Cancer Institute and the Committee on Growth have been kept informed, and the American Registry of Pathology will receive biopsy material for examination by a group of consulting pathologists. Similar arrangements have been made for the review of X-ray films obtained in this study.

With such exhaustive projects in operation and with many other investigators continuously seeking new information on cancer and related cell abnormalities, many and diversely interesting approaches are being made to the problem. For example, studies are being made on animals to determine the influence of heredity, carcinogenic compounds, nutrition, and possibly even viruses on tumors. Thousands of pure chemicals and other substances have been synthesized, isolated, or extracted as treatment measures. Treatment has ranged from hormones to bacterial filtrates, colchicine, podophyllin, urethane, nitrogen mustards, and radioactive elements. Even substances such as

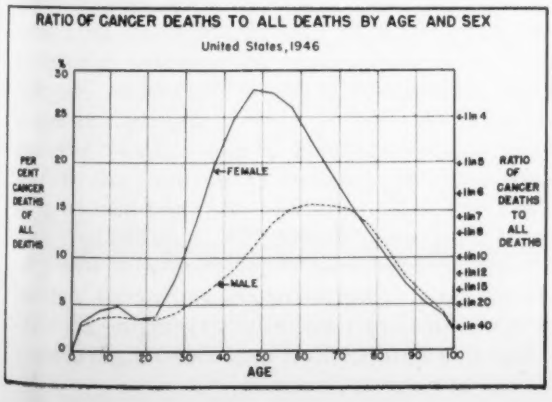
the antireticular cytotoxic serum of Bogomolets (ACS) and the endotoxin of *Trypanosoma cruzi* ("K.R.") have been subjected to scrutiny as possible therapeutic agents.

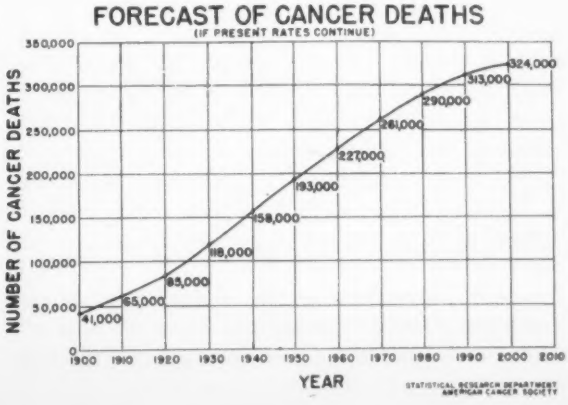
Sometimes promising agents later prove toxic or otherwise disappointing, such as has been the case for urethane in the treatment of chronic myelogenous leukemia. Attempts also have been made to develop technics or substances that are specific for the unwanted tissues; thus, some have searched for radioactive isotopes that would be absorbed by the cancerous process and not by the surrounding healthy tissue. Further work obviously is needed in this phase of cancer research, but at least one group of researchers claims to be able to distribute as desired radiation in the liver, spleen, and bone marrow by varying the particle size and the compound. Radioactive iodine appears to have selective action when properly administered. Hormones of the androgen family; rutin (which is supposed to aid in the control of bleeding following exposure to radiation); substances such as "Fraction X" (it resembles methylcholanthrene under spectroscopic examination) from cancerous human livers; the inactivation of enzymes such as beta-glucuronidase (this enzyme is related to the activity of the so-called "sex" hormones which have been shown capable of developing cancer in mice); the use of toluidine blue to counteract bleeding following an overdose of X-rays; the development of radioactive gold; the use of isotopes for the treatment of polycythemia; the use of irradiated zinc to study leukemia; the use of urethane for the treatment of leukemia (and the subsequent discovery that this chemical causes pulmonary edema in leukemic mice); the use of radioactive diiodofluorescein in the diagnosis and localization of brain tumors, and irradiated cobalt (which may be as effective as radium and is more abundant and cheaper) also are items of discussions involving cancer. The use of radioactive isotopes has become so important in today's research that a training course has been organized at Oak Ridge, Tennessee, for those who may handle the materials.

Occasionally enthusiastic reports appear which later require modification, as has been suggested elsewhere in this article. Unfortunately, such reports mislead the hopeful, who are ever anxious to leave proved treatment in favor of the new ideas that may only result in death; or, if individuals with questionable reputations are involved, serious financial loss may ensue. Furthermore, it is sometimes necessary for renowned and careful researchers to evaluate the newer proposals to obtain a more realistic appraisal. Such waste of valuable time is unfortunate.

Until recently the effective treatment of cancer consisted of the use of surgery to remove the offending tissue and the employment of radium or X-rays to affect unfavorably the growth of the malignant cells. From time to time there have appeared reports of miraculous "cures" from some simple chemical or from a strange mixture of botanicals, biologicals, or even earthy material. None of the "cures" so far has resisted careful scientific scrutiny, and sooner or later they have disappeared, although often not before irreparable damage was done to many sufferers. Usually the claims for cure were based on the results observed in individuals whose maladies were incorrectly diagnosed. Occasionally, a concoction was used in persons who experienced spontaneous recovery from their affliction. Such spontaneous recoveries are yet to be explained satisfactorily by those trained in biology and pathology, but it is known that they do occur rarely, without treatment.

The problem of trying to determine specific and effective chemotherapeutic measures for cancer is complicated by the lack of knowledge that exists concerning the growth of cells, normal as well as abnormal, and the mechanism by which cancer





invades other tissues. Cancer cells do not become organized in orderly fashion like the cells in the normal body organs, and yet they seem to obtain nourishment. Furthermore, there are various kinds of tumors which often seem to behave independently of each other. In addition, some tumors cause symptoms such as fever, loss of weight, weakness, and anemia, whereas others result in practically no such signs of disease.

Cancer can be studied in animals—in fact, it can be precipitated in animals by hundreds of agents, from X-ray to simple mechanical irradiation—but findings obtained on laboratory animals cannot always be transposed to humans. It is known that many cancer cells, on chemical analysis, fall within the range of the findings of some normal tissues, although there are differences; for example, the consistently high rate of glycolysis and increased water content in cancer cells. What major differences exist still remain to be solved by the development of more acute chemical and other tests.

Cancer chemotherapy can be approached in several ways, such as direct destruction of the cancer cell, prevention of invasion, interference with growth, and by other means. The best attack remains yet to be determined. It does seem apparent that the most effective agent has not been developed, nor has the most effective method of attack, or attacks, been discovered. It is possible that specific treatment may have to be initiated for each type of cancer and perhaps for the individual, so that ultimately cancer may be subjected to a barrage of treatments in the same way that infectious diseases are now assaulted by chemotherapy. One thing is certain, however: researchers interested in the control of cancer are now standing on the brink of some remarkable discoveries, and these will surely become known within a comparatively short time.

AUSTIN SMITH
Council on Pharmacy and Chemistry
American Medical Association

FIBERGLAS IN DENTISTRY

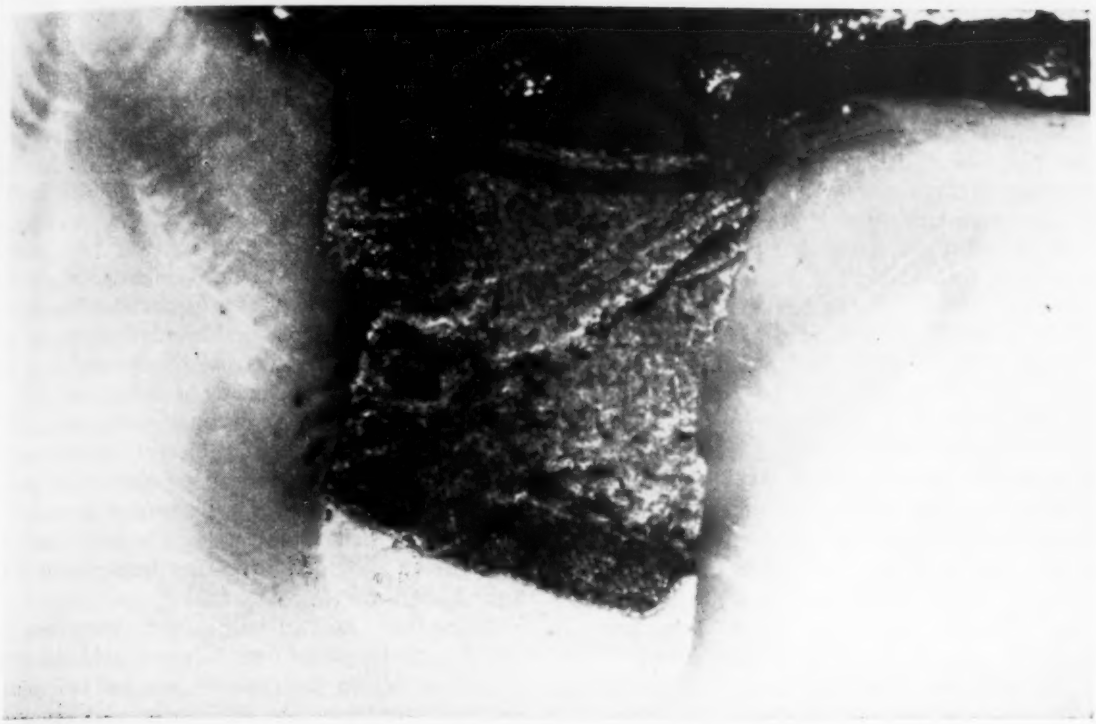
THE quest for new products for dental application is virtually continuous. Through constant research, additions to the materials used in prosthetic dentistry have become numerous in recent years. Not quite as many new products have reached the field of operative dentistry, however.

In operative dentistry, for almost a hundred years, the search has been pursued for a suitable root-canal filling material that would possess, among other necessary properties, the one of great dimensional stability. From the historical standpoint it is of interest that since 1847, when gutta-percha was first introduced into dentistry, a number of other materials, in quest of a better one, have been tried. Included in these experiments through the years were silver amalgam, asbestos, balsam, bamboo, cement, copper, cotton, crystallizable substances, gold, indium, ivory, lead, paper, paraffin, pastes, pitch, rosin, rubber, spunk, thistles, wax, and wood. And as early as 1859 root canals were occasionally filled with condensed cotton saturated with creosote.

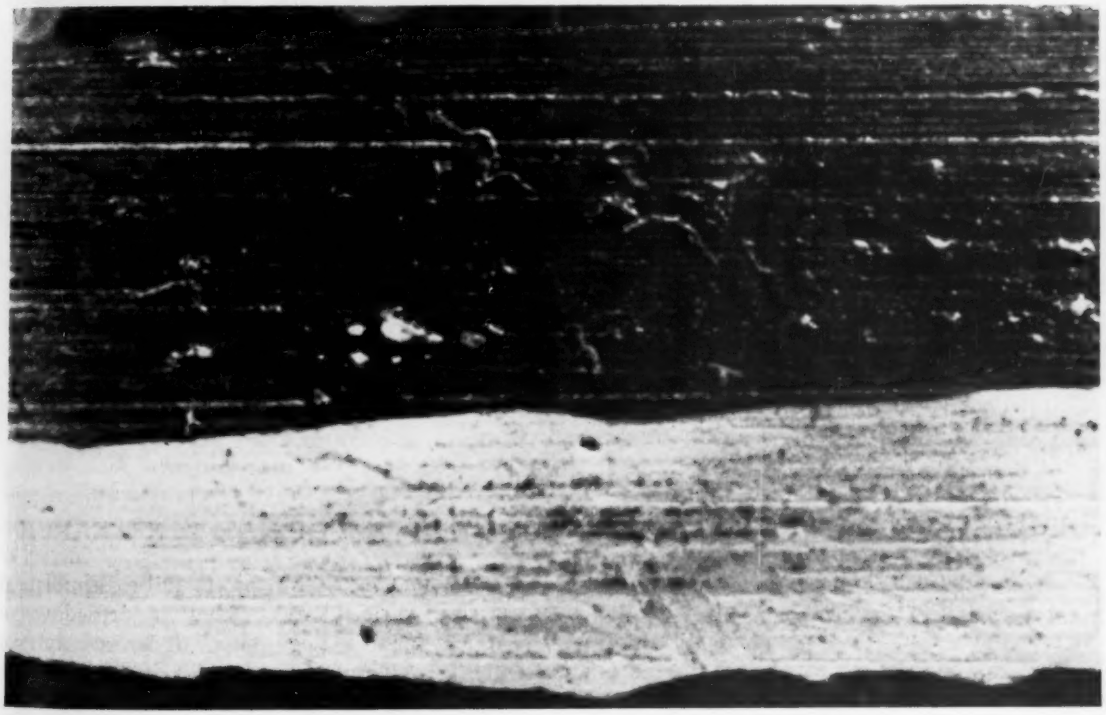
Of this diverse group of materials, gutta-percha is the most widely used for filling root canals. It it used for this purpose in the form of points and small pieces, in a solution of chloroform or eucalyptus. The Council on Dental Therapeutics of the American Dental Association, however, will not accept root-canal filling materials that may undergo significant volumetric change. On page 175, *Accepted Dental Remedies, ADA* (13th ed.), we read: "A volatile solvent, such as chloroform, would tend to evaporate and thus cause a significant change in the volume of a root canal filling."

For an improved root-canal filling material Fiberglas serves as a reinforcing material in a capacity comparable to that whereby steel reinforces concrete. Fiberglas is glass in a fiber or filament form. It is an inorganic, nontoxic, nonallergenic, nonsensitizing, and chemically stable substance that produces no harmful effect upon human tissues. It is pliable and possesses great tensile strength and a high degree of dimensional stability. Fiberglas is nonhygroscopic and noninflammable. The individual fibers do not absorb water; Fiberglas is therefore easily sterilized and resterilized. Glass is not classed as a carcinogenic substance. In medicine, Fiberglas materials have been used for measurement of nitrogen loss in exudate from burned skin; tracer threads in surgical sponges; experimental surgical sutures; culture of microorganisms; blood plasma filters; airborne cross-infection control; penicillin production; Fiberglas-plastic artificial limbs; and insulation of sterilizable closed motors.

Glass fibers possess the greatest tensile strength-weight ratio of any commercial material, natural or synthesized by man. Fibers averaging 23/100,000 inch in diameter have a tensile strength of more



Tooth section showing silver amalgam filling in crown and Fiberglas mass base. × 25.



Section showing Fiberglas mass used as a base under silver amalgam filling. × 25.

than 250,000 pounds per square inch. Experimental fibers have been produced with a diameter of 2/100,000 inch and with tensile strength considerably higher.

The glass fibers possess remarkable dimensional and physical stability. At tension approaching breaking strength the fibers show an elongation up to 3 percent. High tear strength and dimensional stability and resistance to moisture, heat, chemicals or oil are responsible for the utilization of glass fibers in dentistry. In the selection of a root-canal filling material, great dimensional stability is a cardinal property for consideration. For this purpose a root-canal filling has been made, and used experimentally and clinically, consisting of zinc oxide, eugenol (or beechwood creosote), a trace of rosin, and Fiberglas hammer-milled to 1/16-inch lengths, superfine yarn, clean glass without treatment. (Some Fiberglas has been treated with a water repellent.) The physical appearance of the Fiberglas is not unlike that of white cotton wadding. The filaments are about 3 microns in diameter, and the material is very pliable.

To make the Fiberglas mass, the ingredients without the Fiberglas are first spatulated to a medium thick mass and the Fiberglas is then worked into this mixture. It will be noticed that at this stage the mixture becomes a little thinner as the Fiberglas is incorporated. To obtain the desired consistency, more zinc oxide is added with more Fiberglas as necessary. The resulting putty-like mass can easily be divided into any-sized portions or small particles without shredding. The mass is now ready for use as a root-canal filling material, as a base under metal restorations, as a temporary filling, or as a capping over exposed healthy pulps. To reduce the setting time of the Fiberglas mass, zinc acetate to a minimum of 0.5 percent of the solid portion is added. As a root-canal filling material, clinical evidence has proved the Fiberglas mass to possess the following advantages: plasticity, comparative ease of manipulation, ready conformity to the contour of the canal; no evaporation, as in chloroform-gutta-percha mixures, during filling and X-ray checking procedures; great dimensional stability, assuring intactness of a filled canal; insolubility in tissue fluids; radiopaque property, which permits X-ray recording of the stages of filling and upon completion; does not absorb moisture; is impervious to fluids; has no capillarity; filling material can readily be removed from the root canal if necessary.

It has been further clinically demonstrated that the Fiberglas mass makes a dependable temporary filling material. Considerable edge strength and wear-resisting tendencies make such reinforced fillings useful in the treatment of certain cavities in deciduous teeth. The substance seems to have a density closely comparable to that of dentine, as condensed gold-foil restorations have been placed in teeth in which the Fiberglas mass was used as a base. As a protective base under silver amalgam fillings the Fiberglas mass has been found clinically satisfactory.

After being treated with a water repellent, Fiberglas can be placed over cohesive gold foil in the container before the cork or stopper is inserted, giving better protection than cotton wadding.

In conclusion, it can be stated that it has been demonstrated that the great dimensional stability and the high insulation property of the material make the utilization of Fiberglas of distinct value for the dental purposes described.

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HARRY MAETH, D. D. S.

Mosinee, Wisconsin

THE EARTH SCIENCES PROGRAM OF THE OFFICE OF NAVAL RESEARCH

ON August 7, 1946, the Office of Naval Research was permanently established by the Seventy-ninth Congress through Public Law No. 588. At the same time the old Office of Research and Inventions, established in 1945, was abolished. As interpreted from the legislative charter for the Office of Naval Research, one of the primary functions of the Office is to establish fundamental research projects and to stimulate research in various ways, such as by providing government-furnished equipment under research contracts, providing necessary military transportation, and making available to scientists surface craft, aircraft, and submarines whenever a justifiable need arises under a research contract. One other prime method of stimulating research has been the

organization and carrying out of symposia upon various scientific problems that confront scientists in industry and universities today.

The field activities under the cognizance of the Office of Naval Research are The Naval Research Laboratory at Anacostia, D. C.; the Underwater Sound Reference Laboratory at Orlando, Florida; the Special Devices Center at Sands Point, Long Island; and the branch offices at Boston, New York, Chicago, San Francisco, Los Angeles, and London, England. From this it can be seen that we are spread fairly well over the country, with one arm reaching into Europe.

The headquarters office in Washington is divided into three main groups: Administrative, Patents, and Research. Under the Research group is the Physical Sciences Division, which is divided into branches that are concerned with Physics, Nuclear Physics, Mechanics and Materials, Mathematics, Chemistry, Fluid Mechanics, Electronics, and Geophysics. It is the Geophysics Branch that has charge of the Earth Sciences program. We have arbitrarily separated meteorology and oceanography into sections of their own. We do not refuse to call these fields earth sciences, but for reasons of our own we prefer to include in the earth sciences those fields, such as geology, geography, vulcanology, glaciology, gravimetry, etc., which are fairly well earth-bound.

Before discussing the earth sciences program, however, it may be well to speak of the philosophy of the Geophysics Branch, which necessarily is a part of the philosophy of the entire Office. In the first place, we try to avoid soliciting research projects; we prefer instead to have the ideas for these projects spring spontaneously from the minds of the scientists of the country. When this occurs, we are confident that the scientist is interested in the work that he proposes to do and we can feel sure that the work will be carried out to its logical conclusion. Second, we try to avoid telling the scientist how to carry out his project. And, third, we do not place restrictions upon the publication of scientific results, unless, of course, these results are of a classified nature, in which case we try to warn the scientist in advance that his publication will quite likely be curtailed. We thus allow him to choose whether he wishes to carry on the work.

It may be well to mention also that the Geophysics Branch has gone through its stage of expansion. We can no longer take on new research projects at the same rate indulged in a year and a half ago. We can do some new work, but in every case we try to support only the best of the good projects that come to our attention. Eventually it will become necessary to drop one old project for each new one supported, but that day has not yet arrived. At the present time we are still welcoming the submission of new research proposals, with the warning that they are being considered in competition with proposals from all over the United States, and that most of the proposals we are receiving currently are very good.

Since its establishment in 1946, the Geophysics Branch of the Office of Naval Research has allocated a share of its research funds to the support of the earth sciences. During the past two years a total of ninety-seven research proposals in the earth sciences have been received. Of this total, forty-two projects have been supported. Some of these have already been concluded. The number of projects now active are distributed among the various sciences as shown in Table 1:

TABLE 1

Geochemistry	5
Gravimetry	3
Seismology	7
Tectonophysics	2
Terrestrial magnetism	4
Geography	2
Geology	11
Instrumentation	3

In order to indicate the disposition of funds in the Geophysics Branch, I have constructed two diagrams. Figure 1 shows the percentage distribution of funds among the earth sciences during the past two years. This is intended to show only the order of magnitude of support in the various fields. Note that I have differentiated between geology and the sciences that deal more particularly with the physics of the earth. This graph shows that each of these earth sciences is receiving a substantially equal amount of funds. Such small differences as exist can be attributed to the fact that it costs more to pursue some types of research than others, and that a greater number of proposals for research have been received in some fields than in others. Geology is somewhat low in the percentage of funds received. This is not because research proposals in geology have not been received, but because of the fact that the Geophysics Branch believes that such sciences as stratigraphy, paleontology, and the like fall more logically within the purview of the Geological Society of America and the U. S. Geological Survey.

Figure 2 shows the percentage distribution of funds by agencies. This graph indicates that almost two thirds of the funds available are going into universities and institutions. Those funds

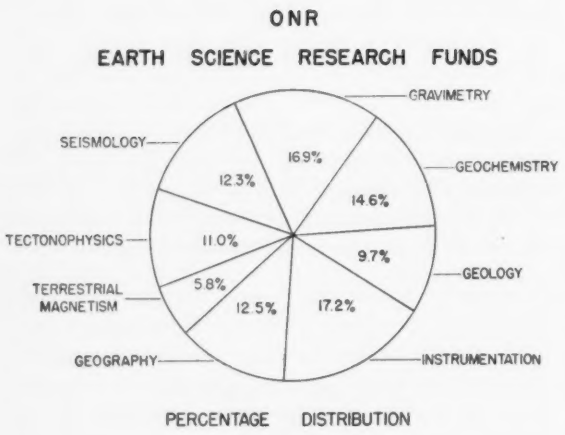

FIGURE 1

going to other government agencies are for the most part confined to specific instrumentation development, which cannot conveniently be done at a university.

Turning now to some of the specific projects that have been supported during the past two years, I shall have space only to report on a few examples from the entire program, but these examples have been chosen as a representative cross section.

In geochemistry, Dr. J. F. Goldsmith, at the Department of Geology, University of Chicago, has essentially completed one phase of his work on the disordered state of silicates. Working with melilite solid solutions, he has shown that as much as 15 percent of $Na_2Si_3O_7$ will go into solid solution with gehlenite and that, at the other end of the isomorphous series, akermanite will not form a solid solution with the same material. Professor Goldsmith discusses some of the factors involved in the reported high Na_2O content in some of the melilites toward the akermanite end of the series in a paper published in the *Journal of Geology* for September 1948. His paper also discusses the possibility that gehlenite may take as high as 10 percent calcium aluminate into solid solution.

In the field of gravimetry, the data now being collected by Professor Maurice Ewing and his associates at Columbia University, when compiled, will give us a better understanding of the shape of the geoid and some of the problems associated with the orogenic zones of the earth's crust. To date, nine gravity-measuring cruises on board U. S. Navy submarines have been completed, and the tenth cruise began last December. Cruises made up to the present have been along the eastern coast of North America, in the Caribbean from Balboa to Trinidad, in the region of the Bahamas and the Straits of Florida, down the western coast of South America from Balboa to Valparaiso, and currently across the southwest Pacific. No report has been received on the number of stations occupied on the recent Pacific cruises, but through June 11, 638 stations had been completed from the nine cruises made.

One of the important projects in seismology under ONR is that being conducted by the Carnegie Institution of Washington under the joint directorship of Drs. Merle Tuve and Roy Goranson in cooperation with the Naval Ordnance Laboratory. The work is concerned primarily with measurements of the thickness of the earth's crust by means of artificial explosions. Instrumentation having the proper characteristics was developed as the first phase of this project. After development, the second phase has been to determine the layering of the crustal structure around the District of Columbia and the Appalachian Highlands. A total of thirty-two seismic shots, ranging in size up to 4,000 pounds, have been made. Indications are that the granitic layer in the Washington, D. C., area is 10 km in thickness, the first basaltic layer extends on down to 24 km, and that the second basaltic layer extends down to 42 km, or to the depth of the Mohorvicic Discontinuity.

A project in the field of geography that will be of considerable incidental interest to all scientists is project CIMA, or the Coordinated Investigation of Micronesian Anthropology. This work is under the directorship of Dr. Harold J. Coolidge, of the National Research Council. CIMA is directed toward an understanding of the peoples of the Trust Territories of the Pacific, their past history, and present-day social customs and con-

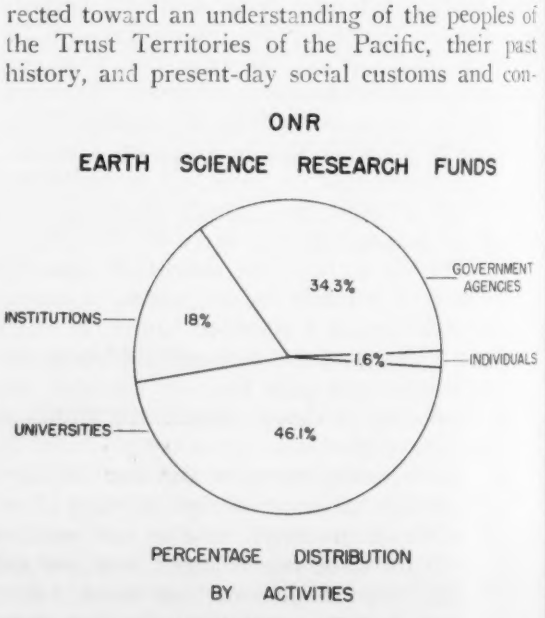

FIGURE 2

ditions of health. Approximately forty-two geographers and anthropologists from twenty-three universities and museums have participated in project CIMA during the past year. The results of this work are being incorporated into a volume known as the *Pacific Ocean Handbook,* which was compiled at the Stanford School for Naval Administration under another ONR project. This volume will be available shortly at the U. S. Government Printing Office and will contain information of great value to those scientists whose main interests lie in the Pacific Ocean areas.

Many geological projects have been sponsored; I can mention each of them only briefly, however.

Professor Francis P. Shepard is pursuing his investigations of the west coast beaches and offshore bottom areas under our large oceanographic contract at the Scripps Institution of Oceanography. I refer you to his recent book entitled *Submarine Geology* (Harper, 1948).

Drs. Belcher, Hemstock, and Kranck, working through the Arctic Institute of North America, have conducted investigations into the geology and permafrost conditions of the Arctic and sub-Arctic.

Professor Robert Sharp, of the California Institute of Technology, has conducted an investigation in glaciology in the Mount Saint Elias Range. The final report of this work has not yet been received.

The U. S. Geological Survey has conducted several investigations in cooperation with the Office of Naval Research. The most outstanding of these projects have been the airborne magnetometer survey of the Aleutian volcanoes and the northern Marshall Island areas and the excellent reconnaissance gravity survey conducted in the Gulf of Mexico just off Louisiana and Texas, which resulted in the location of several new possible salt dome structures out to a distance of about 75 miles from the shore.

I have tried, in this brief discussion, to give a cross section of the program at present being carried on in the earth sciences by the Office of Naval Research. The ultimate responsibility for this program rests with ONR, and more specifically with the six scientists of the Geophysics Branch. It has been found beneficial, however, to seek outside advice in making certain that only the most scientifically worth-while projects are supported and to ascertain that the funds are going to competent scientists, with adequate facilities and staffs.

To this end, the National Research Council established an advisory committee on the earth sciences for the Office of Naval Research. This committee has the responsibility of advising on each research proposal submitted for possible financial support. The names of the members and administrative directors of this committee have been given wide publication in the professional journals of this country and need not be repeated here. It is in order, however, for me to say that the advisory committee has worked long and well in discharging its voluntarily accepted responsibilities; the members are due a vote of thanks from the geologists and geophysicists of the country for their valuable assistance in the direction of public funds along worth-while channels.

GORDON G. LILL

Geophysics Branch
Office of Naval Research
Washington, D. C.

BOOK REVIEWS

THE HISTORY OF SCIENCE IS SCIENCE

Readings in Biological Science. Irving W. Knobloch, Ed. 449 pp. $3.00. Appleton-Century-Crofts. New York.

THIS anthology is designed to provide supplementary reading material for liberal arts students taking an introductory course in biology. With the exception of the first chapter, which includes selections from the works of Hippocrates, Aristotle, Pliny, Leeuwenhoek, Darwin, and Huxley, the bulk of the book is made up of extracts from the writings of modern authors, fifty-eight in all. Many of the authors are professional biologists and teachers, some are physicians, and a few are professional science writers.

The subject matter is classified under fifteen chapter headings as follows: Biological Background; Life and the Cell; The Structure and Function of Higher Plants; Nutrition; Circulation; Nervous and Endocrine Control of the Body; Reproduction; Embryology; Heredity; Eugenics; Evolution; Ecology; Health and Disease; Economic Biology; and Biological Philosophy.

Among the authors whose writings appear may be mentioned Donald C. Peattie, S. J. Holmes, Henshaw Ward, Russell M. Wilder, A. J. Carlson, Emanuel Radl, T. H. Morgan, A. Scheinfeld, W. M. Krogman, W. Overholser, B. Jaffe, J. S. Huxley, and many others.

Brief biographical notes and a reading list appear in an appendix. There is no index.

In his aim of selecting materials characterized by readability and popular appeal, the editor has been eminently successful. One may be permitted to question, however, the success of Dr. Knobloch in selecting a group of readings which will actually contribute to the student's ability to understand and think about the problems of science in our present society. In his introduction, the compiler points out that "World War II has shown us the important fact that the human mind is capable of performing astonishing feats when put under pressure." If this view is correct, then it would seem that the readers for whom this book is intended should be able to handle even more difficult material than is here presented. The jaw muscles are hardened not by custard but by chewing on tough meat. The development of a "tough-minded" society capable of wrestling with the problems of today is accomplished by hard, not easy, reading.

If a second edition of this book is called for, it is hoped that the compiler will consider the inclusion of some less popular but possibly weightier discussions than are contained in the present book. Selection from the vast amount of material available will not be easy, but the results would justify the extra effort. There is no educational task today as important as that of imparting something of the spirit of science and of scientific inquiry to those who will, as adults, not follow the profession of science or aspire to the title of scientist.

MORRIS C. LEIKIND

Library of Congress
Washington, D. C.

The Shipwright's Trade. Sir Westcott Abell. xii + 219 pp. Illus. $4.50. Cambridge Univ. Press. New York.

THE title of this excellent book may be misleading to many Americans, as the word "shipwright" has a much narrower meaning in the United States than it has in Great Britain. The book deals with the evolution of ships and the development of the art of ship design and shipbuilding as a whole rather than with the shipwright's part as we use the term.

The book is written down to the ready comprehension of the layman, as the author explains much of the terminology that is peculiar to shipbuilding. It is regrettable that a little space was not also devoted to an explanation of those baffling terms "ton" and "tonnage" as applied to ships.

In Part I the author briefly covers shipbuilding in ancient times and as practiced by primitive people in modern times. In Part II he deals with the wood shipbuilding era and weaves the biographies of some of the distinguished English master-builders into the story. The pages devoted to the Bakers, father and son, the three Petts, Sir Anthony Deane, and William Sutherland are particularly interesting. He describes the steps in the transition of the shipwright's trade from a secret and mysterious craft, handed down from father to son, to an art with its roots well implanted in science. The era of wood and sail in marine transportation reached its climax early in the nineteenth century. The author writes the obituary of this era in the following lyric paragraph: "The wooden structure had reached about its limit, and was not to appear again in marked fashion until much later in the century. Then for a brief spell came the clipper ships, vessels with iron frames and with wooden skins and decks to amaze the world in the Swan Song of the Sailing Ship."

The last half of the book, Part III, treats of iron, steel, steam, and oil in the designing, building, and operation of ships. Biographical sketches of those titans of science and engineering, I. K. Brunel, Scott Russell, William Froude, his son, and of Charles Parsons, enliven the pages. The author mentions only

briefly those in other countries who improved the ship. His principal interest would naturally lie with the British contributions, but it is surprising to find only a paragraph devoted to the Swedish naval officer Fredrik Chapman, who in the United States is regarded as the greatest and most scientific naval architect of the eighteenth century.

Profuse illustrations add greatly to the charm and value of the book. Sir Westcott merits the thanks of all who are interested in the sea and in ships for the enormous labor he must have put into the writing of the book. He is to be congratulated on the result achieved.

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Washington, D. C.

The Life of Science. George Sarton. vii + 197 pp. $3.00. Henry Schuman. New York.

THIS collection of essays by Dr. George Sarton, professor of the history of science at Harvard University, is designed to provide the general reader with a better understanding of science—its history, scope, purpose, and methods.

Beginning with essays devoted to the story of the spread of understanding, the book covers such matters as the story of early discoveries, the role and importance of special methods and instruments in science, and the relation of these searching activities to other activities of man—in medicine, in religion, in art, and in politics. In this sense the history of science becomes in part the history of civilization, as emphasized in the subtitle of the book.

Following this overview of scientific development, the author documents scientific progress with several biographies of men of science, pointing out that the history of mankind may be divided into (1) political history, or a history of the masses, and (2) intellectual (scientific) history, or the history of a few individuals. Political history, unfortunately, has claimed the main attention of historians, he says. Intellectual history, therefore, needs to come into its own, for it is in intellectual history that one finds the essential aspects and story of human progress.

Political vicissitudes, wars, revolutions, natural catastrophes, are for most men events of primary significance, Dr. Sarton continues, for the reason that man feels directly affected by such occurrences. Yet it is the discoveries of a Galileo or a Newton which, by transforming man's outlook, constitute the cardinal events of the world's history. This is the *essential* history of mankind—and it deserves to be better known.

This small, erudite, highly readable book deserves a place on the required reading lists of all students of science, whether in college or beyond it, as an aid in the extrication of self from time-narrowness. For the history of science, as Dr. Sarton puts it, even more than ordinary history . . . familiarizes us with the ideas of evolution and continuous transformation of human beings; it makes us understand the relative and precarious nature of all our knowledge; it sharpens our judgment; it shows us that, if the accomplishments of mankind as a whole are really grand, the contribution of each of us is, in the main, small, and that even the greatest amongst us ought to be modest. It helps to make scientists who are not mere scientists, but also men and citizens.

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Exploring Electricity. Hugh Hildreth Skilling. vi + 277 pp. Illus. $3.50. Ronald Press. New York.

A PLEASANT surprise awaits the readers of *Exploring Electricity*, by Dr. H. H. Skilling. The author has a real literary style that is seldom found among textbook authors. Even if the story were not one of exceptional interest, the author's way of telling it would hold the reader. *Exploring Electricity* thus takes on a live, vital quality in telling the stories of the men who make up electricity's family tree. It has none of the forced, labored, and obvious effort of a scientist trying to step out of character and temporarily replace the studied, meticulous, and cold accuracy which is inherent in science with the feel of the pulse of life and the vagaries of individual humans.

The story—and it is a real story—takes the development of the key discoveries and advances in electricity from their earliest beginnings in ancient times through the release of atomic energy in the bomb. Not only do you get the "feel" of such great names as Franklin, Galvani, Volta, Ampere, Faraday, Henry, Maxwell, Hertz, Bohr, Fermi, and Meitner as living people hemmed in by human weaknesses and nobilities, you see how their contributions complement each other to achieve real progress. Not once does the author forget and drop back into those purely technical passages which would leave the nontechnical reader high and dry—particularly dry. Nevertheless, technical readers will find pleasure in the way the author's own technical proficiency has enabled him to give the story the cross checks and tie-ins necessary to those who know the field.

Checking over electrical textbooks written by the author, your reviewer found an interesting and unusual thing. Here and there in the mathematical and scientific material composing the text are inserted paragraphs of a vital type which bring in the lives and accomplishments of the men who have made electricity live. In fact, almost a whole page can be found in one text covering Faraday, Ampere, and their relationship to Maxwell and his hypothesis.

Not only is this a book which anyone who has any interest whatever in electricity should read, it is a book that should be collateral reading for all whose studies take them into that field.

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CORRESPONDENCE

S. 247

Now that the National Science Foundation is before the Eighty-first Congress, it is appropriate that scientists also keep it actively in mind. On February 25, S. 247 was reported out of the Senate Committee on Labor and Public Welfare. It is virtually identical with the bill that was passed unanimously in the Senate in the spring of 1948, and it was frankly introduced without any changes in content or in phraseology because it had such an easy time getting through the Senate. Perhaps scientists, who are more intimately concerned with its provisions and its significance, should review it more critically than the senators.

Like its predecessor in the Eightieth Congress, S. 247 is claimed to be a compromise bill. The odds are in favor of its passage, and there is definite reason to believe that it will not be vetoed, even though it is not the type of legislation that the President is known to favor. Direction of Foundation affairs is vested in a board of twenty-four civilians, who will serve on a part-time basis, and who will determine policy. Functioning as the active administrator of Foundation activities is a director, who will be appointed by the President and who will apparently have dual responsibilities to the President and the board. The duality of this position makes it a rather unattractive post and creates administrative problems which any executive would instinctively avoid.

As in all the earlier bills that have passed one or both houses of Congress, the social sciences are not specifically included; and, as if to justify the omission, the bill stresses the promotion of "basic" research. It may be questioned whether basic and applied science can be so sharply differentiated in a Foundation which should be charged with the responsibility of formulating national policy in scientific matters.

S. 247 also provides (Section 14, Subsection (1)) that "The Foundation, after consultation with the Secretary of Defense, shall establish regulations and procedures for the security classification of information or property (having military significance) in connection with scientific research under this Act, and for the proper safeguarding of any information or property so classified." The wisdom of extending security classification into new areas of scientific research may be seriously questioned and viewed with some alarm. Certainly, a recommendation that has been made by the American Federation of Scientists should be weighed carefully, and scientists should express themselves freely on this important problem to their representatives in Congress, and, more especially, to the members of the House Committee on Interstate and Foreign Commerce, to whom this legislation will be referred. The Federation of American Scientists has urged that this section be amended to read: "It shall be the general policy of the Foundation not to give continuing support to research requiring security classification. When any research under its auspices is deemed by the Foundation, in accordance with such national policies as may be established by Congress, to require security classification, the Director shall consult with the Secretary of Defense to determine the appropriate agency to which support of the research should be transferred. Pending such transfer, security classification and procedures shall be determined by the Director after consultation with the Secretary of Defense."

Although a great deal of scientific advice has been contributed to the senators (notably Senator Smith of New Jersey) who have formulated this bill, it is important that all scientists familiarize themselves with its contents. There has been inadequate expression of opinion, and it seems simpler to organize a reasonably satisfactory and generally acceptable Foundation at the start than to tamper perennially with an imperfect organization. In the Seventy-ninth and Eightieth Congresses, congressmen complained that scientists were inarticulate. If they remain inarticulate while National Science Foundation legislation is under consideration, they must assume full responsibility for the kind of legislation they get.

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HOOP-SNAKE STORIES

In his very interesting paper on "America's Mythical Snakes" Mr. Moore states: "There appears to be no classical or European analogue of the American hoop-snake story." It may be true that no written record is to be found on the subject, but verbally such stories certainly do exist. Some fifty years ago, when I grew up on a farm in northern Sweden where the common viper (*Pelias berus*) occasionally was seen, small children were earnestly requested, when seeing a snake, always to run uphill. If one were running down a slope, the snake might form a hoop and catch the runner. It is impossible to judge in what degree the warnings were really in earnest, but that at least some people believed in the stories seems likely. However, when we boys had reached the mature age of twelve to fourteen years, snake hunting became a good sport, and then, I think, the respect for hoop snakes had vanished.

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INTERESTED

I am an interested, even though from an educational standpoint a quite unqualified, reader of this magazine. A number of the articles are technically beyond my full understanding, but many offer me mental food obtained from no other source, and stimulate my thinking to reach out and beyond my everyday life; my work, my house, my garden. Yet this thinking is also a part of these simple activities and enriches them.

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Correction: February issue, page 119, line 40, for "6 percent," read "60 percent."